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DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

GEOLOGY AND ORE DEPOSITS

OF THE

ELKHORN MINING DISTRICT, JEFFERSON COUNTY, MONTANA

BY

WALTER HARVEY WEED

WITH AN APPENDIX ON

THE MICROSCOPICAL PETROGRAPHY OF THE DISTRICT

BY

JOSEPH BARRELL

EXTRACT FROM THE TWENTY-SECOND ANNUAL REPORT OF THE SURVEY, 1900-1901
PART II—ORE DEPOSITS

WASHINGTON
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GEOLOGY AND ORE DEPOSITS OF THE ELKHORN MINING DISTRICT, JEFFERSON COUNTY, MONTANA.

By Walter Harvey Weed.

CHAPTER I.

INTRODUCTION.

FIELD WORK AND ACKNOWLEDGMENTS.

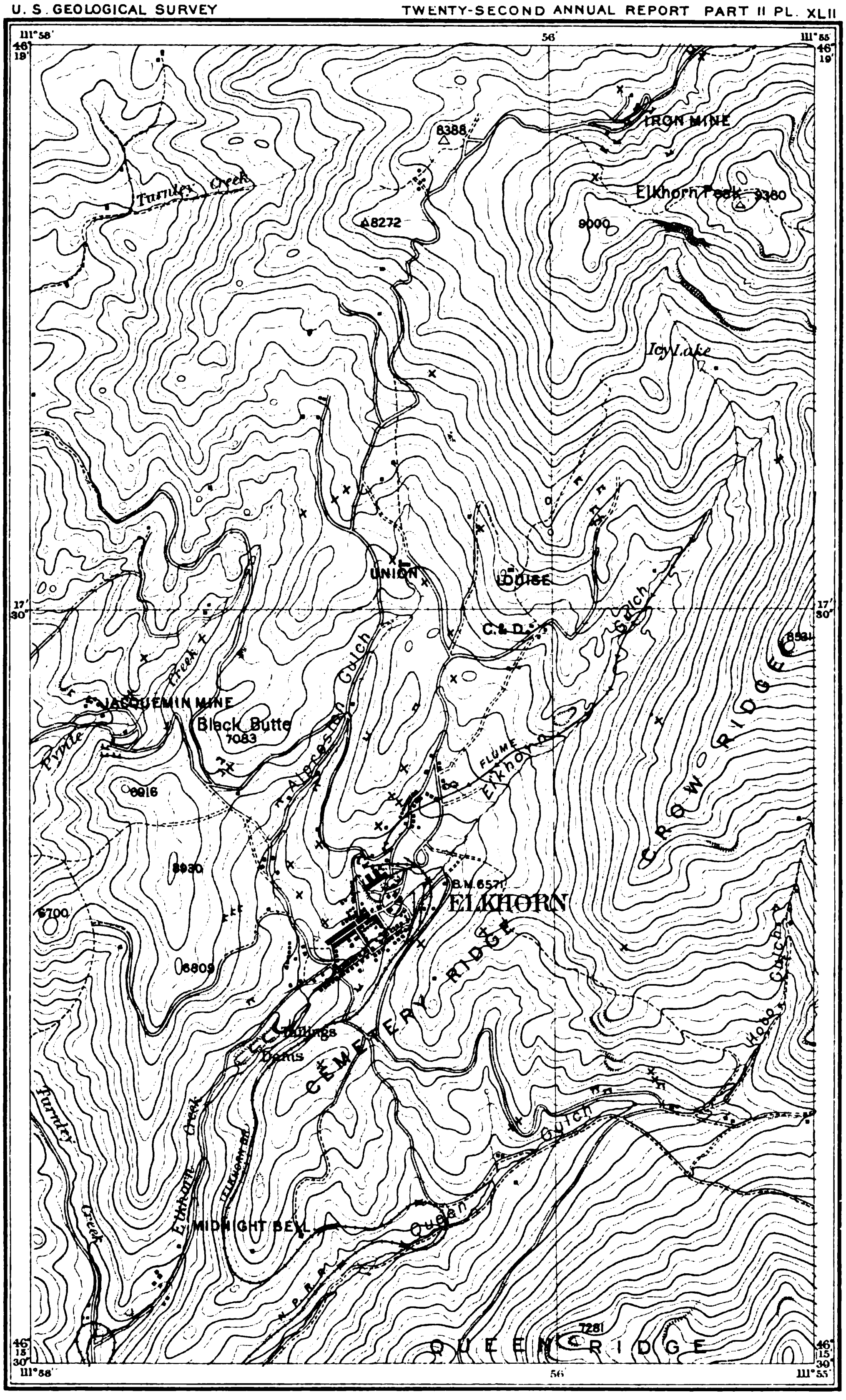
The Elkhorn district was first visited by the writer in the summer of 1896, while studying the general relations of the granite area in which the Butte ore deposits occur. Mr. Walter S. Kelley, superintendent of the Elkhorn mine, called attention to the value of an investigation of this property, whose extensive development and interesting geological occurrences make it in some respects unique among the ore deposits of Montana. It was found that the ore deposit occurs on the borders of a great area of granite, and that in the immediate vicinity of the deposit there has been successive intrusions of igneous rock, breaking up through folded sedimentary and earlier igneous rocks. The district thus offered peculiarly favorable opportunities for a study of the relations of the igneous rocks to one another and of the effect produced by such intrusions upon adjacent sedimentary rocks. In 1897 a second visit was made to the district, and a fortnight was spent in a reconnaissance of the entire area and a determination of the more salient features of its geology. The observations made at this time confirmed opinions previously formed, and detailed mapping and study of the district were determined upon. In the summer of 1899 Mr. R. H. Chapman was detailed to make a topographic map covering the more interesting geological features of the region immediately about Elkhorn. The writer planned to do the detailed geological mapping himself, but the necessity of further study of the Butte copper deposits prevented his spending the summer upon this work. Therefore he took to the district Dr. Joseph Barrell, who was acting as field assistant for the season, and went over the ground with him, indicating the distinctions to be made and the problems to be worked out. The areal distribution of the rocks was mapped by Dr. Barrell during the months of August and September, and great credit is due to him for the care with which the obscure boundaries of the different rocks have been traced out. At the same time he made careful studies of the relations of rock masses, of the changes in the igneous rocks resulting from contact metamorphism, and of possible assimilation of material by the intruding magma. The detailed facts upon which many of the inductions made in this report rest were, therefore, gathered by Dr. Barrell. The underground work was done by the author. The petrographic study of the rocks was made by Dr. Barrell, under the direct supervision of Prof. L. V. Pirsson, in the petrographic laboratory of the Sheffield Scientific School of Yale University. The geological notes obtained by Dr. Barrell, together with this report upon the petrography of the rocks, formed the basis of a thesis prepared by him in partial fulfillment of the requirements for the degree of doctor of philosophy. The paper thus prepared has been largely drawn upon by the writer in preference to the original field notes, while the petrographic report is the same as that of the thesis, save only that much of the purely speculative portion has been omitted.

The topographic map of the district (Pl. XLII) includes an area of 1½ by 2½ miles, on a scale of 1:32500, or about 2 inches to a mile, the relief being shown by 50-foot contours. Where the Elkhorn district is mentioned in these pages this area is meant. All the more important prospect pits are located and the more important geological features are included within the area selected.

The chemical analyses in this report have been made in the laboratory of the Geological Survey by Dr. H. N. Stokes.

Thanks are especially due to Mr. Walter S. Kelley, former manager of the Elkhorn mine, for his hospitality and for kindnesses too numerous to mention. The author is indebted to him for the use of the mine maps and for valuable specimens of minerals and ores, also for the use of a room kindly placed at his disposal, as well as for many personal hospitalities. Thanks are also due to Mr. William Davey, former foreman of the mine, and to Mr. Thom Tyack, assistant foreman, for many courtesies.

This report will be regarded by some as an account of an exhausted and worked-out district, as the Elkhorn mine, the chief producer, after a productive period of about twenty years, was closed down and abandoned. In 1901, however, it was reopened, and promises to be again a producer. The other properties are as yet in the prospect stage, and, though promising, did not offer sufficient exposures and data for a complete report. It has seemed advisable, however, to present somewhat fully the facts concerning the Elkhorn mine, as they will be of interest in connection with the future development of other properties in the country. The depth to which the mine was worked and the lateral extent of the development offered peculiarly favorable



TOPOGRAPHIC MAP OF THE ELKHORN DISTRICT

Topography by R. H. Chapman
1899

Scale
0 ½ 1 MILE

Contour interval 50 feet

JULIUS BIEN & CO. N. Y.

conditions for study, and no apology is needed for presenting an account of a mine which has yielded such large amounts of the precious metals and which must ever be regarded as one of the big mines of Montana.

GEOGRAPHIC POSITION.

The Elkhorn district is situated in the center of Jefferson County, in the central portion of the mountain region forming the western part of the State of Montana. The town of Elkhorn, which is in the center of the district, lies about 18 miles east of Townsend, a town on the Missouri River and on the main line of the Northern Pacific Railway. It is 20 miles southeast of Helena and about the same distance northeast of Butte. It is accessible by a branch line of the Northern Pacific Railway, and is about 12 miles east of the town of Boulder, which is on the Montana Central division of the Great Northern Railway. The accompanying map (fig. 72) shows the situation of the district with respect to the main drainage lines and mountain ranges of the State. Crow and Elkhorn peaks rise to an elevation of 9,500 feet only a short distance to the north and northeast of the town, being the highest peaks for many miles around. These two peaks are the culminating summits of a group of mountains lying west of the Missouri River Valley and isolated from the neighboring ranges of the Rocky Mountains by broad, open valleys on the north, east, south, and west. This group, to which the name Crow Creek Mountains or Crow Mountains is often applied, has a crest line in shape somewhat resembling a horseshoe, with the opening facing eastward and trenched by Crow

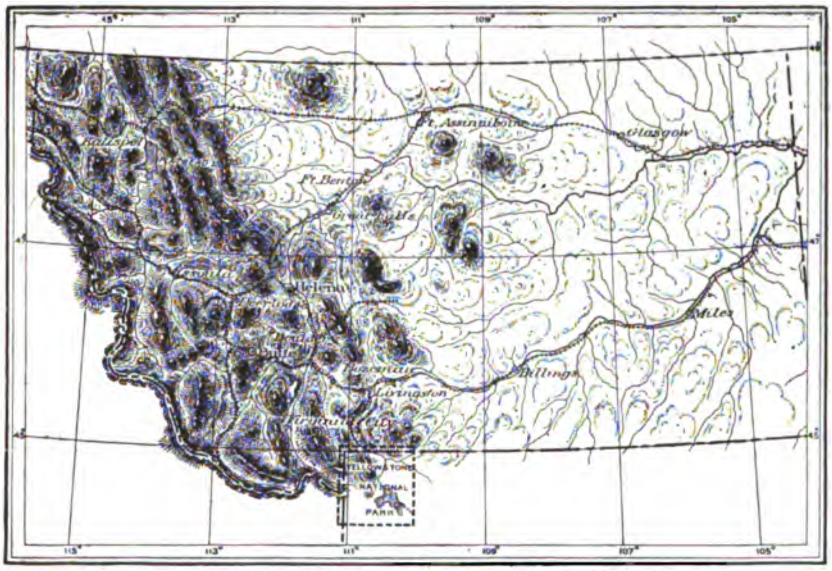


FIG. 72.—Index map of Montana, showing location of Elkhorn district.

Creek, a tributary of the Missouri. This mountain district, which owes its elevation primarily to the folding of sedimentary rocks, but chiefly to the durability of the finer-grained igneous rocks which cap its summits, is drained by streams which are generally radial to its flanks. On the west, however, a long north-south fault, marked by the drainage way of Prickly Pear Creek and Boulder Valley, separates it from the complex of mountain peaks and ridges known as the Boulder Mountains. It is thus seen that the Crow Mountains not only lie well within the mountain region of the State, but are a unit both topographically and geologically, and not merely a part of some larger district.

TOPOGRAPHY.

The district is one of great relief, as is well shown on the topographic map, Pl. XLII. In general the slopes, though steep, are not precipitous. While the rocks are usually well exposed, there is considerable soil and vegetation. Owing to the elevation of the region, it receives abundant precipitation in the form of rain and snow and is often the scene of midsummer snowstorms even when the adjacent lowlands are bathed in sunshine. As might therefore be imagined, the climate is somewhat rigorous and the winters are long. For this reason there is an abundant drainage, which is all concentrated in the stream known as Elkhorn Creek, while immediately outside of the area mapped Crow Creek and Prickly Pear Creek also take their heads. The district, though small, shows the usual peculiarities of drainage noticed where igneous rocks and limestones are found close together. In the former rocks the streams are perennial, while in the latter the drainage ways carry running water only in times of heavy rain or melting snows. There is a concordant association of plant life, the limestones being in general bare and arid and the igneous areas usually well wooded and covered with an abundant herbage, but this is dependent on rainfall, which is a function of altitude, so that the general statements given above are true only where the elevations are similar. In the lower part of Elkhorn Creek, where it enters the broad, open valley of Boulder River, the areas of both igneous and limestone rocks are arid and devoid of all arboreal vegetation.

Elkhorn is one of the most picturesquely situated mining towns of the State. It lies near the head of a mountain valley at a point where a sudden broadening occurs. To the south the gulch is narrow and canyon like, while above it changes from a moraine-dammed gorge to a high mountain amphitheater. Nestling close up under Elkhorn and Crow peaks, at an elevation of 6,500 feet above the sea, it receives tribute from many cloud banks which, drifting across the lower mountain country to the west, are caught by Elkhorn Peak. The scenery is not typically alpine, though rugged and picturesque. The view from the town is, however, a broad one, including a wide stretch of valley and a mountain range to the south.

The town is built upon a steeply sloping bowlder apron, the front of a moraine that incloses the upper valley of the creek. The slopes near by are parked and wooded, and are in strong contrast to the arid and glaring limestone hills seen in the valley to the south. The most striking feature of the scenery is Elkhorn Peak, whose summit rises 3,000 feet above the town and is about 1½ miles distant from it. The mineral wealth of the district is found in the altered limestones near their contact with gabbro-diorite intrusions and where broken through by offshoots from the mass.

HISTORY.

The Elkhorn district was prospected early in the history of the State and numerous quartz locations were made in the years preceding 1870, but the district did not attract attention until the A. M. Holter lode became a producing mine. This property, later known as the Elkhorn mine, has been the principal and, in fact, almost the only producer of the district, and was for many years one of the prominent silver mines of the country. The history of the mining industry of this district is therefore the history of this mine. The Elkhorn property was sold by its original locators to A. M. Holter, after whom the claim has been named. Mr. Holter organized the Elkhorn Mining Company, and the mine has since been known as the Elkhorn mine. A 5-stamp wet crushing free-milling plant was erected by the first owners, and as the surface ores were free milling and yielded readily to simple amalgamation, satisfactory results were realized in the early history of the property. With increased depth, however, the oxidized ores became refractory and the loss in treatment became as high as 50 per cent of the silver values. In 1881 the mine was developed to a depth of 300 feet, and the nature of the ore made it evident that a new mill would have to be erected and chloridization adopted. Owing to a disagreement among the owners and the necessity of enlisting new capital, the property was idle for the greater part of the year 1882, though it yielded 4,285 ounces of fine silver during that year. In 1883 the property passed into the possession of the Elkhorn Mining Company, a new hoist was erected, and a 10-stamp chloridizing mill was put up, with a capacity of about 11 tons a day. The ore was stamped fine, roasted, and amalgamated in combination pans without grinding. The result was a saving of 90 per cent of the values and a bullion product aggregating $188,375 in silver and $2,320 in gold for the first ten months after installment. The bullion product was 900 fine in silver, with a little gold, the principal impurity being copper.[1]

The old Elkhorn Company subsequently increased its battery to 20 and then to 25 stamps and worked the mine down to the 800-foot level, where lean ore was encountered, and some doubt was expressed as to whether the property was not worked out. In 1888 the Montana corporation sold out to a new company organized in London, which took the name and property of the old corporation, remodeled the mill, and instituted a policy of vigorous development, under which the mine has yielded 6,500,000 ounces of silver and 5,000 ounces of gold since 1888. The total production of the mine has been computed by Mr. Walter S. Kelley, the manager of the property, from the company's books. The figures are given in round numbers only, and those for the earlier period are only approximate.

---

[1] Report of the Director of the Mint for 1884, p. 302.

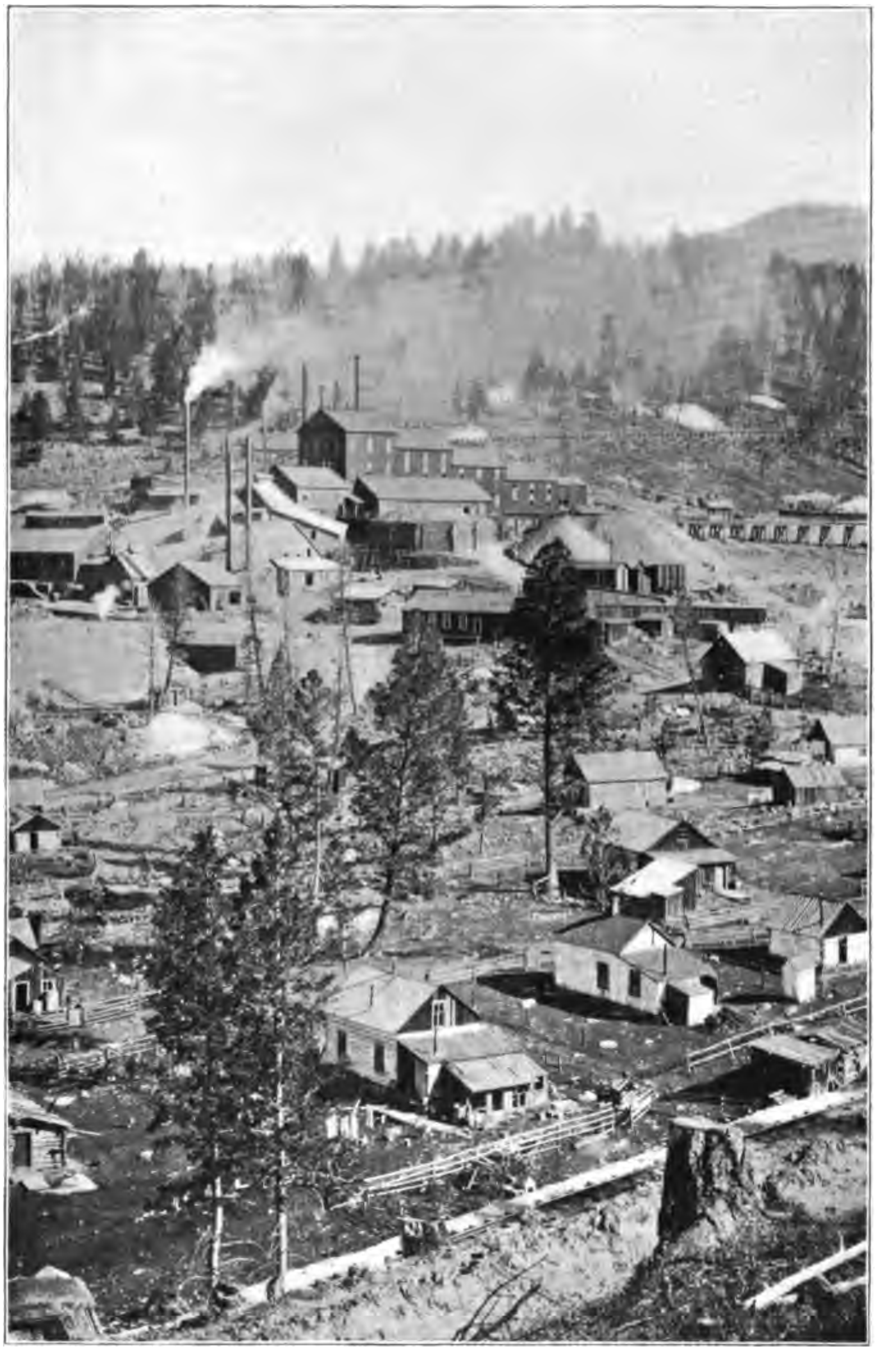
From 1884 to January, 1900, the mine was in continuous operation, save for a short time in 1886, when an accident to the pumps resulted in the flooding of the mine up to the 500-foot level for several months.

In 1896 the ore in sight was nearly exhausted, and preparations were made to abandon the mine, but Mr. Walter S. Kelley, who at that time became general manager of the property, by careful exploration work disclosed new ore bodies, and continued to work the property until December, 1899. In the autumn of 1899 it became apparent that the expense of pumping, which necessitated heavy fuel bills, combined with the small extent and low grade of the ore in sight, would not warrant the further operation of the mine. The cost of the ore extracted had steadily risen during the last few years until in 1898 it reached a total of $15.60 per ton, while the expense of milling increased to $9.50 per ton. It was therefore decided to close down and abandon the property.

The development of the Elkhorn has played an important part in the settlement and betterment of the State. The monthly pay roll aggregated over $15,000, as besides the men employed at the mine and mill a large number of wood choppers were regularly at work. The town of Elkhorn, a settlement with a population of about 600, was built and maintained practically by this one mine, and the supplies shipped to the district for mine and town kept the railroad line busy for many years. The passing into history of this great property is felt not only at the town of Elkhorn, but in the ranches, for whose produce it furnished a market, and in the parts of the State from which it drew supplies.

The former inaccessibility of the district, situated as it was in the heart of the mountains and until recent years remote from railroad communication, deterred active prospecting for a long time; moreover, in the early years of the Elkhorn mine, supplies, particularly salt, were very expensive, so that the cost of treatment was heavy.

In 1886 the Northern Pacific Railway built a branch line to Wickes to get the ore-carrying business of the Alta and Comet mines. About two years later the marvelous development of the Butte copper deposits induced this company to begin an extension of this branch



ELKHORN MINE AND MILL.

southward to that city. At the same time the Montana Central, now a part of the Great Northern system, was under construction, and a railway-building contest began, with Butte as the objective point. The Montana Central secured the more favorable right of way, and the Northern Pacific line, after being built to Bernice, was not completed. Both roads pass through Boulder, the county seat, 12 miles west of Elkhorn, so that a year later the Northern Pacific Company was induced to build a branch line through the Boulder Valley and up the gorge of Elkhorn Creek. The building of this road was a difficult piece of engineering, as the grade to be overcome was excessive, but by the use of short loops a road was constructed on which short trains could be hauled. A triweekly train service was established, making it possible to ship the silver-lead ores which were discovered in great abundance in the deep workings of the Elkhorn mine, and which were also found to a limited extent in other properties in the district.

PRODUCTION.

The successful development of the Elkhorn mine resulted in very energetic prospecting of the adjacent claims during the first few years of its existence. The report of the Director of the Mint for 1884 mentions 12 mines, all close to the Elkhorn, which were said to show well-defined ore bodies, carrying good values in silver and sometimes in gold and copper, and which were at that time developed by prospect shafts over 20 feet deep. Of those noted in that report, the Keene, Union, and C. and D. have been developed into mines from which ore has been shipped at various times, but the properties have thus far proved disappointing to the owners, and their yield has been insignificant compared with that of the Elkhorn mine. The C. and D. is the only one from which any returns of production are available. A small smelter was built in 1886 and run for a short time upon the ores from this mine. The product for 1886 is given in the report quoted as $4,068 worth of bullion. For 1887 the same authority gives the product of the C. and D. mine as $10,335 in gold and $10,320 in silver, and for 1888 as $2,661 in gold and $10,433 in silver.

In later years the C. and D. has been leased at various times, and the ore extracted has been shipped to custom smelters. The ore, however, has been too low grade to work profitably, and it is only when pockets of galena have been found that any profit has been made in the workings of the property. The other properties of the district have been worked at various times in the last twenty years, but only for short periods, and have not been developed into producing mines. An exception should be made of the Elkhorn Queen, which lies over the ridge beyond Queen Gulch, just outside the limits of the area mapped.

The following tables give the yearly production of the Elkhorn mine:

Yearly production of Elkhorn mine from 1882–1889.

Years.	Silver.	Gold.
	Dollars.	*Dollars.*
1882	*a* 4,285	....
1883	(*b*)	....
1884	168,375	2,320
1885	218,828	1,338
1886	276,051	....
1887	(*b*)	....
1888	476,754	6,068
1889	*a* 389,353	4,450

a Ounces. *b* Not reported.

Yearly production of Elkhorn mine from 1890–1900.

Years.	Silver.		Gold.		Lead, smelting ore.
	Mill bullion.	Smelting ore.	Mill bullion.	Smelting ore.	
	Ounces.	*Ounces.*	*Ounces.*	*Ounces.*	*Pounds.*
1890	418,516.02	102,628.81	202.104	168.557	187,214
1891	345,079.62	271,914.98	406.287	485.854	619,054
1892	486,033.01	422,270.17	537.721	519.917	794,305
1893	428,613.07	332,195.98	360.137	349.629	548,382
1894	470,706.99	281,998.43	353.598	259.809	448,311
1895	474,390.68	77,398.77	359.304	79.435	136,554
1896	486,720.95	90,787.29	339.975	85.566	149,367
1897	489,959.78	96,872.10	420.244	109.147	179,341
1898	375,963.04	214,908.89	243.605	230.626	532,429
1899	364,906.08	*a* 193,374.55	258.413	140.380	357,827
1900	20,362.18	....	13.486	....	....
Total	4,361,251.42	2,084,349.97	3,494.874	2,428.920	3,952,784

a Ore shipments.

In addition to the above there was an average of about 7,500 pounds of copper contained in the mill bullion each year.

Production of Elkhorn mine by periods.

Years (inclusive).	Silver.	Gold.
	Ounces.	*Ounces.*
1875-1884	500,000	500
1885-1889	2,000,000	2,000
1890-1899	6,402,000	6,000
Total	[a]8,902,000	8,500

[a] And 4,000,000 pounds of lead.

From what has been stated, it will be seen that the economic geology of the district is almost entirely an account of the Elkhorn mine, and, indeed, not only are the workings of the other properties small, but they were at the time of visit inaccessible. A large number of mining claims have been located and prospecting pits sunk over nearly every part of the district. Thus far, however, the only ore deposits worthy of serious attention appear to be in the areas of altered sedimentary rocks. Small veins have been found near the summit of Elkhorn Peak and in the amphitheater below it, but up to the present time no ore bodies large enough to warrant extensive development work have been discovered. The Jacquemin mines, situated about 2 miles west of Elkhorn, on a branch of Turnley Creek, have shipped considerable ferruginous ore, which was too low grade to work on account of its precious-metal content alone, but which was needed at the smelter as a flux. The iron mines on the north side of Elkhorn Peak are also worthy of attention, as they expose large bodies of rather pure iron ore. As a district, the future can not be said to be bright, as the low-grade character of the ores precludes their treatment at present prices. The gold ore of the Dolcoath is, however, a possible exception.

MILLING.

The Elkhorn ores are of two classes—smelting and milling. The smelting ores consist chiefly of argentiferous galena and are shipped to the smelter. The milling ores are a mixture of silver sulphides and gray copper, and are treated by the ordinary chloridizing process. A careful separation of the ore is, of course, made in the mine, and this, fortunately, is made the more readily because the milling ore is almost wholly quartzose and comes from the hanging-wall bodies. The milling ore is treated at the mine in an ordinary pan amalgamation mill.

In milling the ores the treatment has varied somewhat in recent years, owing to their increasingly refractory character. In general, the process consists in a dry stamping of the siliceous ore, salt being added to the ore as it is fed to the stamps, whence the dry pulp is conveyed directly to the Brückner roasters. The large amount of gray copper and galena in the ore treated in the last few years has made it necessary to use as much as 15 per cent of salt. In the free ores from the upper levels of the mine 5 per cent was sufficient. The roasted ore is taken in cars to the cooling floor, where it is left in heaps for ten to fifteen minutes, then holed by inserting a bar vertically and then horizontally, making a free air passage through the center of the heap. The heap is subsequently leveled down to a thickness of 1 to 2 feet and then trenched by ditches. The cooled ore is then conveyed in wheelbarrows to the pan room, where it is mixed with salt and sulphuric acid and put in amalgamating pans, lime being added to clear the quicksilver. After grinding in the pans the pulp is drawn into settling pans, which, when half full of pulp, are filled up with water and stirred slowly for half an hour. The top peg is then pulled out and a stream of water run in.

The cost of treatment has steadily increased as the ores became more refractory. This is largely due to the increasing amount of salt used. Thus in 1896 the cost of salt per ton of ore milled was $1.88, rising to $2.14 in 1897, and to $2.22 in 1898. Fuel cost but $1.05 in 1896, rose to $1.10 in 1897, and to $1.40 in 1898. These two items account for the increase from $7.17 in 1896 to $9.49 in 1898.

The careful returns made by the mine manager, Mr. Walter S. Kelley, to the company, show in great detail the cost of treatment per ton of ore milled. In considering the following table, which is copied from the manager's report for the calendar year 1896, it should be remembered that the ore was extremely base. The table shows the amount of ore treated, of bullion produced, etc.

Work performed by Elkhorn mill in 1896.

Batteries (20-stamp) in service	315 days, 9 hours.
Pans in service	357 days, 15 hours.
Ore crushed	13,762 dry tons.
Salt used	2,249 tons.
Average amount crushed per stamp per day	1.745 tons.
Average assay value of pulp	38.435 ounces silver per ton.
Pulp panned	13,718 dry tons.
Average assay value of tailings	3.435 ounces.
Portion saved according to assay	92.775 per cent.
Portion saved according to bullion returns	92.313 per cent.
Silver produced	486,721 fine ounces.
Gold produced	339.975 fine ounces.

The details of cost are given as follows:

Analysis of cost of milling per ton of pulp treated in 1896.

Labor account.		Supplies account.	
Superintendence and foreman	$0.3734	Chemicals	$0.0772
Engineers	.2134	Lubricants	.0364
Crusher man	.1571	Illuminants	.0032
Dryer man	.1578	Fittings	.0124
Battery man	.2147	Tools	.0045
Roaster man	.1847	Castings	.2308
Cooling floorman	.1569	Iron and steel	.0186
Carmen	.3166	Lumber	.0143
Amalgamators	.2131	Charcoal	.0387
Pan helpers	.1568	Belting	.0245
Assayer	.0722	Quicksilver	.3486
Storekeeper	.0437	Salt	1.8800
Millwright	.0512	Fuel	1.0572
Machinists	.1916	Assay office	.0374
Teams and labor	.1453	Stables	.0240
Watchmen	.0803	Office and incidentals	.0763
Tailings dam	.0828	Freight	.0152
Office expenses	.0656	Insurance	.0940
		Machine shop	.0039
		Legal expenses and taxes	.2463
		Sundries	.0538
Total	2.8772	Total	4.2973

Cost of labor per ton	$2.8772
Cost of supplies per ton	4.2973
Total	7.1745

Analysis of cost of milling per ton of ore treated from 1896–1898 inclusive.

	1896.	1897.	1898.
Superintendence, including office expenses	$0.37	$0.4298	$0.5217
Labor	2.4382	2.6475	3.3058
Salt	1.88	2.2187	2.1406
Fuel	1.0572	1.1171	1.3973
Quicksilver	.3486	.4479	.8904
Chemicals	.0772	.0623	.0661
General repairs and supplies		.6323	.7214
Surface expenditures		.1567	.2034
Taxes, insurance, and legal expenses	.2463	.2599	.2423
Total	7.174	7.9722	9.4890

The fuel cost is increased also, owing to increased depth of the mine, the larger amount of water due to new water courses cut in prospecting upper levels, and the increased use of compressed air.

Analysis of cost of mining per ton of ore hoisted from 1896–1898, inclusive.

[Based upon total expenditure in mine.]

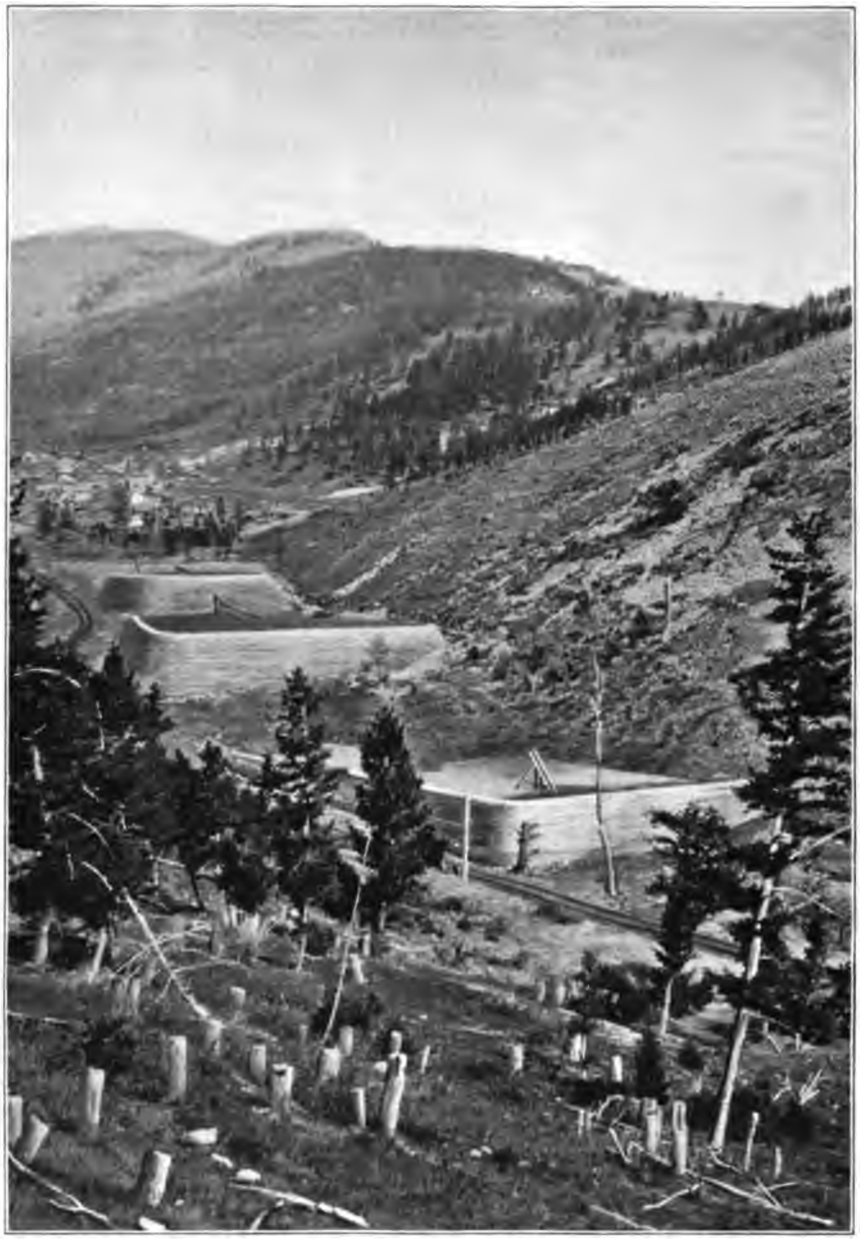
	1896.	1897.	1898.
Superintendence, including office expense		$0.7163	$0.7833
Mine labor		9.1486	9.0269
Ore-house labor		.6212	.7246
Fuel		3.0343	3.0993
Explosives		.6404	.8090
Timber		.0992	.1250
Illuminants		.0788	.0768
General repairs and supplies		.4525	.5362
Surface expenditures		.1495	.1892
Taxes, insurance, and legal expenses		.2732	.2238
Total	$12.384	15.2140	15.5941

The cost of mining was, in 1896 and subsequent years, very greatly increased over that of former years by reason of the exhaustion of the large ore bodies formerly worked; the cost was largely increased, also, by reason of the ore coming from many small stopes and faces.

Amount, contents, and value of ore sold.

Year.	Ore.	Silver.	Gold.	Lead.	Total value.	Value per ton.
	Tons.	*Ounces.*	*Ounces.*	*Pounds.*		
1898	1,700.309	214,908.89	230.626	532,429	$104,945.83	....
1897	715.241	96,872.10	109.147	179,341	48,478.44	$67.78
1896	554.234	90,787.29	85.566	149,367	50,355.59	90.85

A peculiar feature of the reduction plant at Elkhorn is shown in Pl. XLIV. The tailings are impounded by a series of dams built up of sacks filled with tailings sand. The bags are those in which the salt used by the mill is received. Their cost is therefore trifling, and when filled with sand they form excellent retaining walls. These dams are made necessary by the fact that the water is used by the ranchmen downstream for irrigation.



TAILINGS DAMS OF ELKHORN MINE IN GORGE OF ELKHORN CREEK, BELOW THE TOWN.

Shows narrowing of the valley where creek leaves altered limestones and cuts through the quartz-diorite-porphyry. Tailings dams are opposite slide of porphyry débris Main wagon road is seen in bottom of gulch Higher wooded area on mountain covers Carboniferous limestone. Smooth, rounded summit of Crow Peak seen in distance

CHAPTER II.

GENERAL GEOLOGICAL FEATURES OF THE DISTRICT AND ITS RELATION TO THE SURROUNDING REGION.

The Elkhorn district comprises a small part of the southwest end of a group of mountains of very complex composition. For the benefit of the reader who may desire to know the relations of the district to the surrounding region a short résumé of the conditions, so far as they are known from the writer's studies, will be given in this chapter, together with a brief account of the leading features of the district itself. The district lies on the border of the great Boulder granite area, and includes a part of that area and also the borders of an area of folded limestones, shales, etc., which compose the long ridges lying east of Elkhorn and extending to the Missouri River. This area of folded rocks includes rocks of nearly all geological periods and of varied lithologic composition, all flexed in long arches and intervening troughs, forming the S-shaped folds, such as are found in the eastern ranges of the State. These folds can be traced westward and the individual formations readily followed to the Elkhorn district, where the normal lithologic character of the strata is lost as a result of contact metamorphism. The folding of the strata is clearly older than the extrusion of the igneous rocks which break up through them.

The Elkhorn mining district includes a wide variety of rock formations and, small as it is, within its borders is found evidence showing the nature of a long series of profound disturbances which have materially modified the geology of this part of the State. Lying on the western border of a great area of folded sedimentary rocks, the formations seen within its limits include a wide variety of lithologic types, now profoundly altered by later metamorphism, but in part at least traceable uninterruptedly into the normal unaltered formations a mile or two away. The sedimentary record of the earth's earlier history is, however, better studied in the region immediately east, since the Elkhorn region is peculiarly favorable for a study, not of sedimentation or the period of rock folding which succeeded, but of the many and varied events which occurred in a period of dynamic activity, initiated by volcanic outbreaks which, from evidence presented elsewhere in the State, are known to have commenced in early Tertiary time, and after the uplift of the region above the sea and the formation of mountain ranges by folding and synchronous erosion.

The evidence of the magnitude and power of the forces at work during what may fittingly be called the dynamic period of the history of the region is everywhere apparent, and the varied phenomena which resulted are exhibited here better than at any other place known to the writer. The detailed evidence gathered in the mapping of the areal geology confirms by abundant proof the deductions made during the reconnaissance of the district as to the relative age of the rocks and the metamorphic effects produced by the injection of great masses of molten rock.

The sedimentary rocks are devoid of all but the most fragmentary fossil remains, and are so generally metamorphosed that their original character is largely masked. Nevertheless, their sedimentary character is perfectly apparent, their bedding distinct, and the attitude of the beds easily made out. Moreover, while exact correlation of beds is not always possible, there is a general correspondence between the sequence observed here and that at localities near by, notably near Helena and near Whitehall, and the Carboniferous formations have been identified not only by fossils but by tracing the beds into the region of unaltered fossil-bearing strata a few miles southeast of the town.

The sedimentary rocks embrace a part of the Algonkian series known as the Belt terrane[1], and the Cambrian and other Paleozoic formations recognized in the Belt Range are undoubtedly represented here. The Jurassic has not been positively identified and the great series, several thousand feet thick, of altered argillaceous siliceous rocks, which directly overlies the Carboniferous must certainly be in part Cretaceous, for, although no paleontological evidence was obtained, the stratigraphic correlation is convincing. The Tertiary lake-bed deposits found in the larger intermontane valleys of western Montana do not occur in the district described, though found but a few miles to the south. The region probably formed a highland at the time the Tertiary lakes existed, from which the waste of subaerial erosion and probably also the lighter material poured out from volcanic vents were washed down into the Tertiary lake that filled the broad, open valley traversed by the Boulder River below Elkhorn Creek.

The igneous rocks are of several kinds, generally coarse grained, but of very widely differing appearance. The rocks are mostly of common types and present no difficulty in classification. They are of different age and represent successive events occurring in the Tertiary or post-Tertiary history of the region. The oldest rocks are gabbros and diorites, the youngest are aplitic granites. The former break irregularly up through sedimentary rocks and include fragments of them in their mass or resting upon their surface. Volcanic activity

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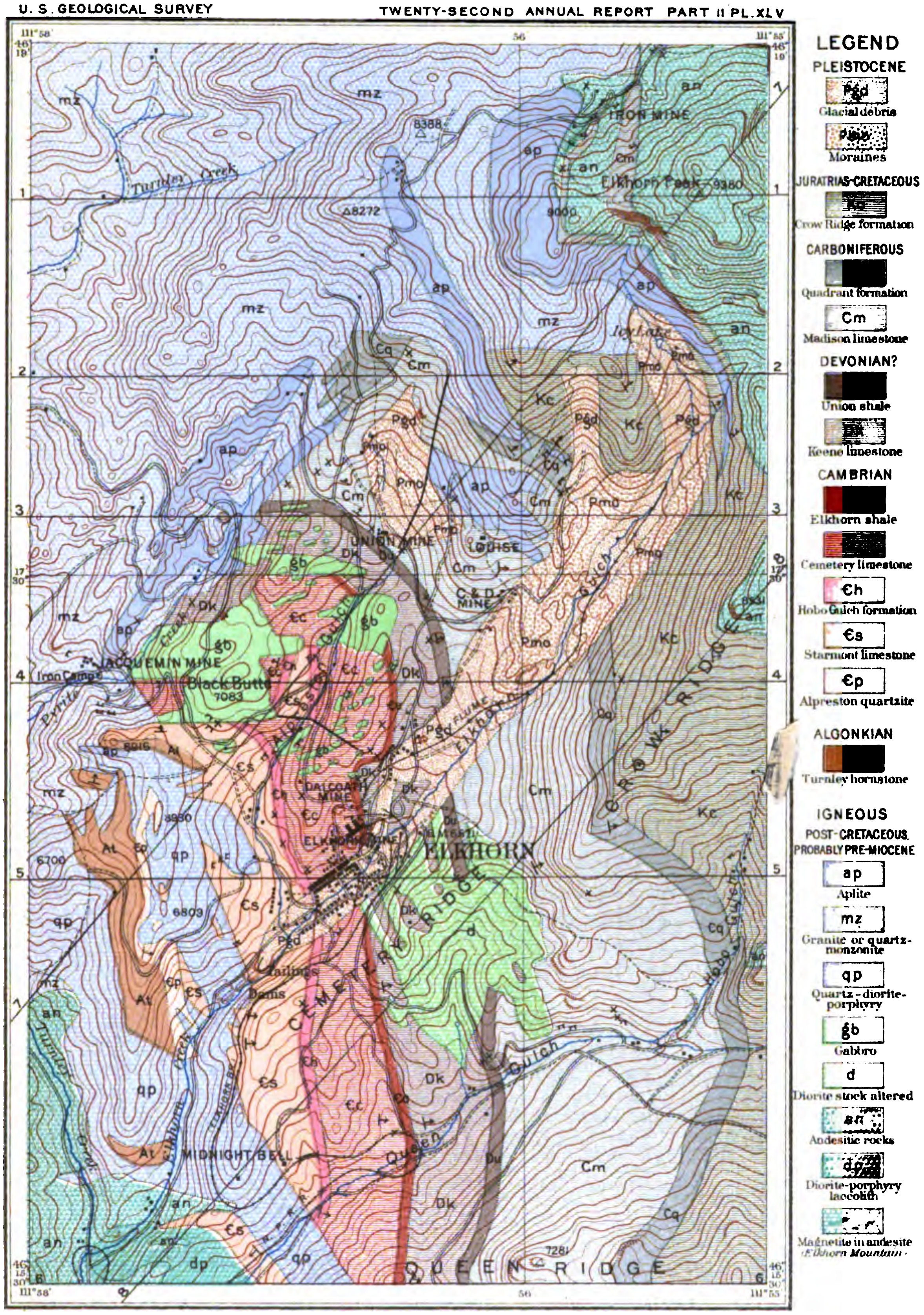
[1] For nomenclature and designation as terrane see Walcott: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 199-244.



GEOLOGICAL MAP OF THE ELKHORN MINING DISTRICT, MONTANA

Scale
0 ½ 1 MILE
Contour interval 50 feet

Walter Harvey Weed, Geologist
Joseph Barrell, Field Assistant

JULIUS BIEN & CO N.Y.

of great power and probably long duration is represented by the andesitic rocks of Elkhorn Peak and of the mountains running south from Elkhorn toward Bull Mountain. The rocks are clearly similar in character to those seen over parts of the Boulder region, and, as elsewhere, embrace lava flows, tuffs, and breccias. The source of these rocks was some vent lying to the west of Elkhorn. These volcanic rocks were at a later period broken through and probably somewhat metamorphosed by intrusions of diorite-porphyry, which broke off parts of the earlier gabbro mass and chilled against the andesitic rocks. The granite is even later, as is clearly shown in several places by including fragments of earlier igneous rocks. The aplite-granite is still later and is the most recent of the igneous rocks.

The origin of the ore deposits of the region is discussed in a separate chapter. Their source is undoubtedly the igneous rocks, very probably the basic igneous rocks of the district, especially the gabbro.

From the résumé just given it is evident that the district offers exceptional opportunities for studying the relations and relative age of the igneous rocks and the effects of contact metamorphism. With a wide acquaintance with the mountainous region of the State, the writer knows of no other place offering such good opportunities for a study of the effects of igneous intrusions upon other rocks and those of sedimentary origin. Indeed, there is good evidence here that the putting in place of the earlier intrusions has been accomplished with so little disturbance that the effects of the magma upon the disrupted rocks in which it intrudes can be particularly well observed. There is no positive proof of actual assimilation of one rock by another, though the field evidence strongly indicates this, as well as the usual metamorphic action.

All the rocks noted, except the granite and aplite, show metamorphism, most intense near the granite and less so away from it. It is evident that the district has been many times heated, but that the most marked effect is due to the last, the granitic intrusions.

The finding of clearly intrusive andesites low down in Queen Gulch and in the valley of Elkhorn Creek below the town shows that the region was a deeply eroded and mountainous one before these early lavas were poured out, and there is reason to believe that the former extent of these rocks was very much greater than at present. The areal distribution of the rocks of the district is shown on the geological map, Pl. XLV. In the following chapters the rock types and formations will be described and their distribution discussed.

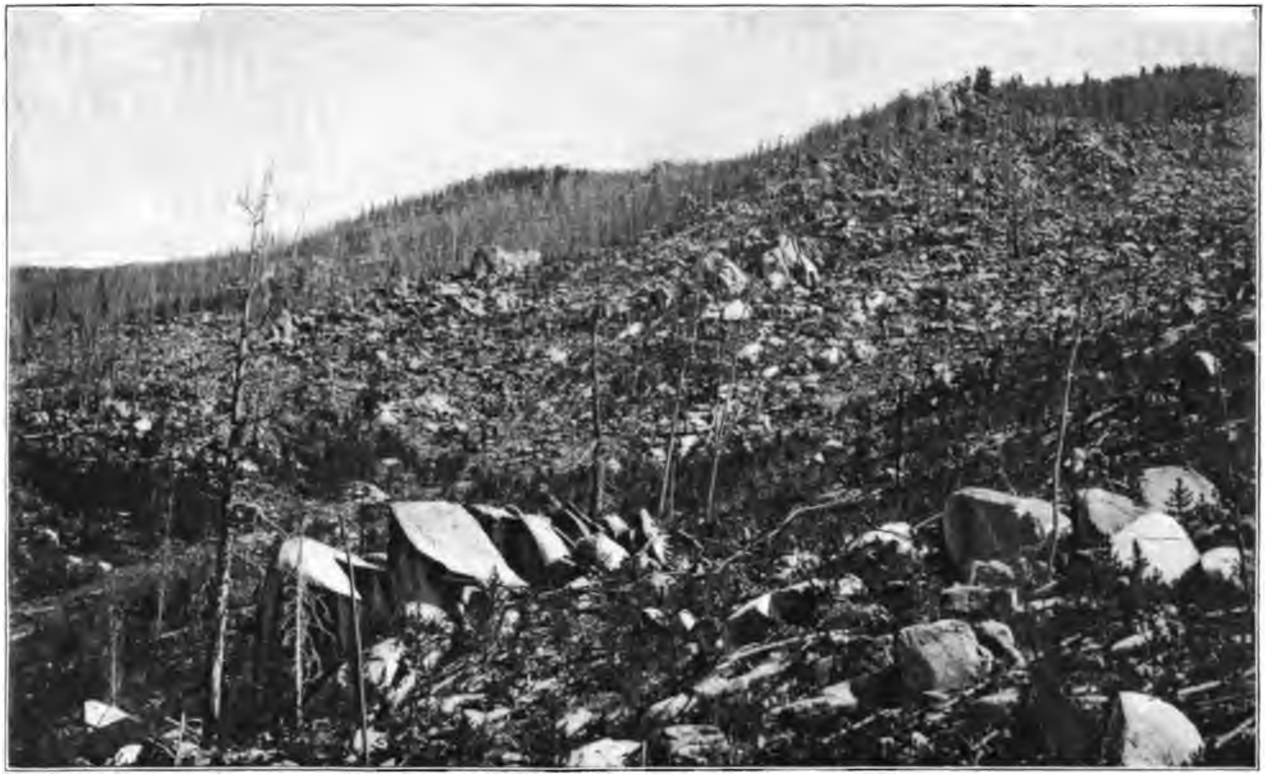
CHAPTER III.

IGNEOUS ROCKS OF THE DISTRICT.

The igneous rocks cover about half of the area shown on the geological map (Pl. XLV) of the Elkhorn district, and, as indicated in the structure sections, they underlie the sedimentary rocks in some areas where the latter are seen on the surface. Their diverse characters, their relations, and their effect upon the sedimentary rocks and upon one another make them the leading feature of the geology of the district. The ore deposits are probably derived from the igneous intrusions, but definite proofs of this connection can not be traced. The igneous rocks are all younger than the sedimentary ones, and if ordinary procedure were followed their description should follow that of the sediments; but, inasmuch as the latter are all altered and metamorphosed by the heat of the igneous intrusions, and hence owe their present characters to them, it has seemed best to give a general description of the igneous rocks first, reserving the account of their microscopical petrography for an appended paper by Dr. Joseph Barrell.

The igneous rocks embrace a number of rock types, varying greatly in appearance and in chemical and mineralogical composition, as a result of original differences in the composition of the magma and of widely varying physical conditions under which the molten material has consolidated into rock. The rocks of Elkhorn and Crow peaks and those seen at the mouth of Queen Gulch are mainly volcanic and represent lava flows and the loose ejectamenta of volcanic eruptions. The other igneous rocks are of intrusive origin and have been consolidated beneath the earth's crust.

The most abundant rock type is one of granitic habit and forms a part of the granite area extending for many miles north, west, and south of Elkhorn. The other rocks are readily distinguished from this and from the andesites by the eye alone, but less readily from one another. With the exception of the gabbro-diorite rocks, which show wide variations in the same rock mass, the rocks are fairly uniform in character throughout each intrusion.



TYPICAL GRANITE AREA AT HEAD OF TURNLEY CREEK.

Showing bowlders due to disintegration along joint planes.

GRANITIC ROCKS.

GRANITE (QUARTZ-MONZONITE).

Definition.—Under the name "granite" are included those coarsely granular rocks, intruded and consolidated at considerable depths below the earth's surface, which have a normal granitic structure and consist of quartz, orthoclase, soda-lime feldspars, hornblende, and biotite. Augite, titanite, and magnetite are present as accessory constituents. The Elkhorn granite is exactly like the granite at Butte in which the copper and silver veins occur. The latter rock has been repeatedly described as a basic granite—one nearly like a diorite in composition. The adoption of the name monzonite for such intermediate rocks makes the new name quartz-monzonite applicable, but the older name "granite," being more generally understood, will be used except in the petrographic description of the rock. The rock is readily recognized, as it is the coarsest-grained rock of the district and contains white feldspars, glassy quartz, black or dark-green hornblende, and dark-brown mica.

Extent and character of surface.—The granite area shown on the map is merely the eastern border of a very extensive granite area lying to the west, extending from Helena on the north to a point 26 miles south of Butte, and from Elkhorn west to the Deer Lodge Valley. This great mass of granite, to which the name "Boulder batholith" has been applied by the writer,[1] is somewhat sharply defined, and with its aplitic forms is the youngest member of the igneous series at Elkhorn, though in many parts of the main area west of Elkhorn it is cut by rhyolite dikes and covered by extrusive masses of that rock. Within the Elkhorn district the granite forms the western flanks of Elkhorn Peak and the rough country west and northwest of the town of Elkhorn. The areas covered by it are readily recognized by the great bowlders which strew the slopes, as shown in Pl. XLVI. The timber, too, is peculiarly indicative in its manner of growth, consisting mainly of the lodgepole pine (*Pinus murrayana*), which rarely attains a diameter exceeding a foot.

Description.—The fresh rock is coarsely granular, of light-gray color, and composed of dark-green hornblende, dark-brown biotite, colorless quartz, and waxy-white and pale flesh-colored feldspar. The grains average about 4 mm. in diameter. The hornblende is more abundant than the biotite. Augite occurs very rarely and is surrounded by paramorphic hornblende. Small grains of yellow titanite are sometimes seen. The rock is not absolutely uniform in appearance, but shows smeary streaks and spots of darker color, which are particularly abundant near the margin of the mass.

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[1] Granitic rocks of Butte, Mont., and vicinity, by W. H. Weed: Jour. Geol., Vol. VII, 1899, pp. 737-750.

The rock is fresh and has suffered little chemical alteration, even where disintegration is prominent.

Chemical composition.—A fresh specimen from the western part of the area shown on the map, analyzed by Dr. H. N. Stokes in the Survey laboratory, gave the following result:

Analysis of granite (var. quartz-monzonite) from near Elkhorn, Mont.

Constituent.	Per cent.
SiO_2	64.31
Al_2O_3	15.44
Fe_2O_3	2.43
FeO	2.58
MgO	2.21
CaO	4.22
Na_2O	2.71
K_2O	4.09
H_2O at 110° C	.19
H_2O above 110° C	.79
TiO_2	.71
CO_2	None.
P_2O_5	.22
S	[a] Trace.
Cr_2O_3	None.
MnO	Trace.
BaO	.07
SrO	Trace.
Li_2O	Strong tr.
Total	99.97

[a] Whether S or SO_3 undetermined.

The analysis is typical of quartz-monzonite and corresponds almost exactly with that of the Butte granite. The mineral composition calculated for it is very nearly the same as that of the Elkhorn rock.

Weathering.—The granite disintegrates readily under ordinary weathering processes, and as it is traversed by intersecting joints rounded bowlders thickly cover the ground wherever the slope is sufficiently steep to admit of the removal of the sand into which the rock disintegrates. The result is a peculiarly rugged scenery, typical of granitic rocks in many parts of the world.

Relative to surrounding rocks, the granites are the youngest of the district and have broken across all earlier masses. These relations are fully discussed elsewhere.

APLITE-GRANITE.

The term "aplite" is used to designate granular or finely granular siliceous granites consisting chiefly of alkali feldspar and quartz. The name is here applied to those lighter-colored granites nearly free from augite and biotite, usually somewhat finer grained than the normal rock, and occurring as dikes and intrusions in it or in the rocks near its border. The rock is, when fresh, creamy white, slightly finer grained than the granite, of sugary texture, and contains very few and small grains of biotite and hornblende. The rock varies greatly, however, in texture and appearance, and, as shown in another chapter in discussing its relationships, is possibly locally enriched by material absorbed and assimilated from the rocks with which it is in contact. It varies from very finely granular structure to a pegmatite. It weathers in rounded surfaces, but does not form the bowlders characteristic of the quartz-monzonites. It is subject to disintegration, and when so altered is easily quarried and dressed.

An analysis made by Dr. Stokes showed the following composition:

Analysis of aplite from Elkhorn, Mont.

Constituent.	Per cent.
SiO_2	76.26
Al_2O_3	12.94
Fe_2O_3	.69
FeO	.13
MgO	.17
CaO	1.10
Na_2O	2.73
K_2O	5.26
H_2O at 110° C	.17
H_2O above 110° C	.43
TiO_2	.11
CO_2	None.
P_2O_5	.06
S	[a] .01
Cr_2O_3	None.
NiO	None.
MnO	Trace.
BaO	.07
SrO	None.
Li_2O	Trace.
Total	100.13

[a] Total S.

DIORITE-GABBRO GROUP.

These rocks form a series in which gabbro and diorite form the end members, with rocks of intermediate character between. The areas occupied by each rock have been mapped separately, but the smaller intrusions near the town are of intermediate character, while the geological evidence indicates that they are all parts of one great mass underlying the altered sedimentary rock seen on the surface.

GABBRO.

Definition.—A gabbro is a granular crystalline rock, consisting essentially of lime-soda feldspar and pyroxene (commonly augite). The Elkhorn gabbro is a dark bluish-gray rock, varying from fine to coarse grain. The most basic variety, found at Black Butte, shows a felted mass of satiny labradorite crystals, with irregularly rounded grains of augite and considerable magnetite. Gabbros commonly show decided variation in mineralogical composition in parts of one mass, and the local modifications might be described as special types. The basic type just noted varies to one showing hornblende and biotite replacing augite and showing some quartz. The texture of the rock is particularly well shown on weathered surfaces, on which the dark augite stands in relief above the dull-gray feldspar. In the coarsest-grained forms the augite grains are so large and abundant as to give the rock a strongly porphyritic appearance. In the finer-grained forms the augite grains are minute and the rock has a pepper-and-salt appearance and texture.

Chemical composition.—An analysis of a typical form of the rock, from Black Butte, has been made in the Survey laboratory by Dr. H. N. Stokes, with the following result:

Analysis of gabbro from Black Butte, Elkhorn, Mont.

Constituent.	Per cent.	Constituent.	Per cent.
SiO_2	47.44	CO_2	None.
Al_2O_3	18.21	P_2O_5	.68
Fe_2O_3	5.37	S	[a] .03
FeO	6.05	Cr_2O_3	None.
MgO	5.53	NiO	None.
CaO	9.98	MnO	.06
Na_2O	2.58	BaO	.08
K_2O	1.17	SrO	.08
H_2O at 110° C	.13	Li_2O	Trace.
H_2O above 110° C	1.08	Total	99.85
TiO_2	1.38		

[a] Undetermined whether sulphide or sulphate.

Occurrence.—Gabbro occurs in several small intrusive masses, apparently breaking up through sedimentary rocks and forming irregular masses called stocks. The largest area, which is a half mile across, is that of which Black Butte is the most conspicuous point. A lesser stock occurs a thousand feet farther north, and another to the east. The ridge between Elkhorn and Preston shows many exposures of an intermediate gabbro-diorite rock, which are thought to be the tops of dike-like intrusions connecting with a general parent mass below.

The rock resists weathering well, but does not commonly form exposures, except on Black Butte, where it occupies a conspicuous position, being visible for many miles around. In the smaller outcrops the rock decomposes somewhat readily, although its resistance to weathering is generally in marked contrast to the more easily altered diorite. Black Butte shows a massive exposure of great blocks and loose masses 5 to 10 feet across, the actual summit being a point with sharp western and precipitous eastern faces. The precise limits of the intrusions are defined with difficulty, owing to the presence of waste from above. The smaller masses show as low reefs or groups of bowlders, seldom prominent.

The Black Butte mass contains many included fragments of sedimentary rock—limestone altered to a mass of epidote and garnet—the sediments about the margin of the gabbro and those through which the dike have come up being all intensely altered by metamorphism. This and the attitude of the strata, which appear to dip inward, all indicate that these different exposures are parts of one mass underlying the entire area in which the exposures are found. The sediments are evidently greatly shattered and greatly metamorphosed, and probably form a relatively thin capping over the main core or reservoir of this rock, the smaller intrusions rising from it and through the cover like the branches of a tree.

DIORITE.

In the workings of the Elkhorn mine and in the railway cut east of the town a very fine-grained dark-gray rock is found which closely resembles the finer-grained forms of gabbro, but which, when studied under the microscope, is found to be diorite. The rock masses mentioned are offshoots of a mass lying east of Elkhorn.

Definition.—Diorite is a plutonic rock which varies somewhat in texture, but is always granular, and consists essentially of soda-lime feldspar, and hornblende. The Elkhorn rock is rather basic and is allied to the gabbros. In the freshest rocks seen it is a dark gray and not unlike the gabbro of Black Butte, but in fresh fracture is easily recognized, as the gabbro shows no white feldspar and is of a uniformly gray tint, while the diorite, when closely examined, is seen to consist of a mass of dark-colored hornblende, augite, and bronzy biotite grains, held together by a matrix of white feldspar, though this is less apparent in the more common, finer-grained forms of the rock.

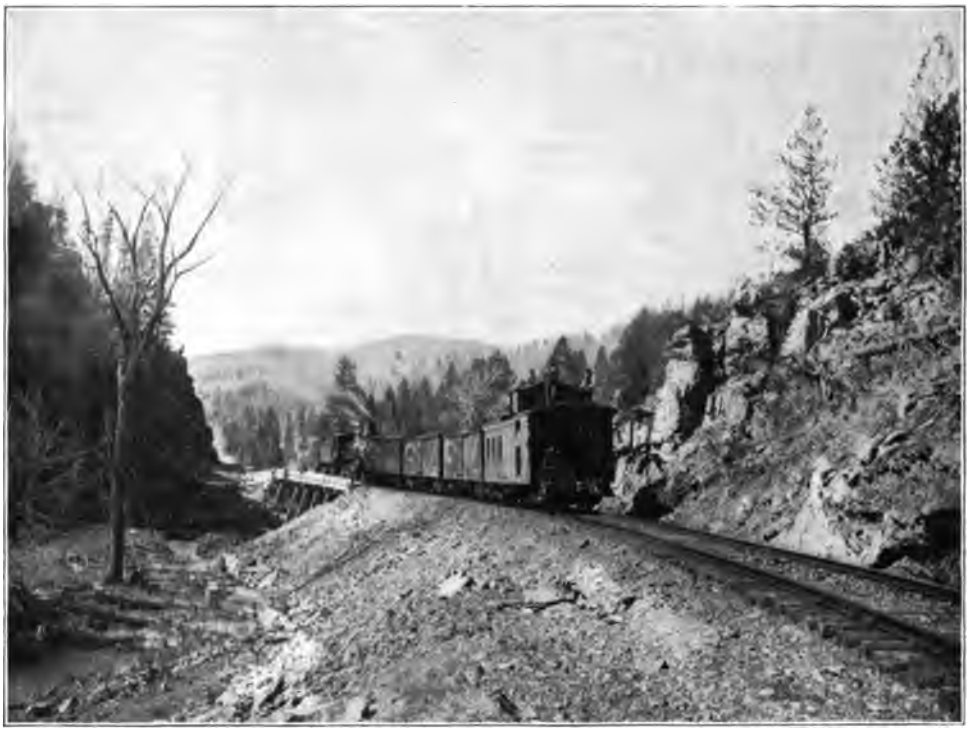
Extent and area covered.—The main diorite area occurs east of the town, forming the ridge and the shallow, grassy amphitheater north of Queen Gulch. The rock weathers readily and decomposes to a soft and porous mass, so that, though exposures are abundant, fresh unaltered material is hard to obtain. The dike rocks also weather readily and are commonly concealed by the limestone débris and soil. The area covered by it is about 3,000 feet across and somewhat longer in the direction of the strike of the stratified rocks, the shape of the intrusion evidently being influenced by the attitude of the sedimentary beds.

The exposures in the railroad cut for one-fourth mile south of the station show an alteration of this diorite. Nucleal masses are seen surrounded by soft and much crackled white, pale-yellow, or yellowish-green alteration products. The same phenomena were observed in the mine workings, 1,250 feet below the surface. They show that the cause of alteration is a deep-seated one, and that it is not a mere surface phenomenon. In the railroad cut just mentioned the altered diorite is lacking southward, but limestones appear cut by diorite dikes, six dikes, varying from 5 to 60 feet in width, being noted intrusive in the upturned strata in the second quarter mile.

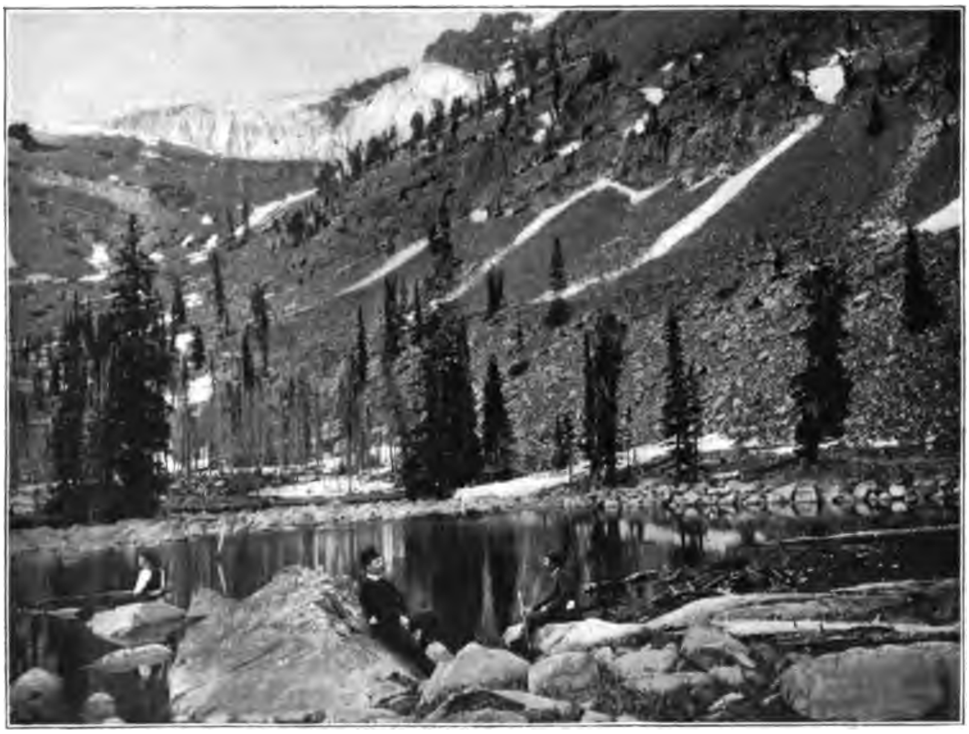
QUARTZ-DIORITE-PORPHYRY.

Definition.—Quartz-diorite-porphyry—using the name "porphyry" in the broad sense adopted by the Geological Survey to designate a porphyritic texture—is a fine-grained rock having the composition of a quartz-diorite (that is, composed essentially of plagioclase feldspar and free quartz, with accessory orthoclase and ferromagnesian minerals), which contains phenocrysts or large distinct crystals, usually of plagioclase and less commonly of augite or other iron magnesian silicates, in a finely crystalline matrix.

Extent and character of surface.—The Elkhorn quartz-diorite-porphyry covers a considerable area in the southwestern portion of the district, where it forms the ridge between Turnley and Elkhorn creeks and the sharp ridge to the east where the railroad crosses from Queen to Elkhorn gulches. It forms talus-covered slopes, in part wooded, but of characteristic appearance, as shown in Pl. XLIV, so that the area covered by it is in a general way easily discriminated from that of the other rocks. The mass is cut through by both Turnley and Elkhorn creeks, exposing a section 800 feet deep across the mass. The gently sloping summit west of the mouth of Alpreston Gulch is covered by soil and vegetation, so that good exposures are not common.



A. POINT OF ROCKS, SHOWING GORGE CUT IN ANDESITES BELOW TOWN OF ELKHORN.



B. ICY LAKE AND MARBLE CLIFFS, ELKHORN PEAK.

The white area is an included mass of marble in andesite; the cliffs on the right are highly altered Mesozoic rocks.

ANDESITIC ROCKS.

Definition.—Andesites are volcanic rocks of porphyritic or felsitic texture, whose crystallized minerals are plagioclase with either biotite, hornblende, or augite, or any two, or all three of the minerals. The andesitic rocks embrace a wide variety of types of both intrusive and extrusive origin. They differ greatly in appearance, but are all closely related in composition and genesis and form part of the great formation covering large areas in the Crow Creek Mountains north and east of Elkhorn; they also form the hills to the southwest of the town and the long and high ridge known as Bull Mountain, which is a continuation of these hills. Collectively they represent the products of a single period of vigorous volcanic activity. Here, as elsewhere in the State, these rocks constitute great mountain blocks, which have been piled upon the earlier rocks in great masses, and which were probably parts of cones now dissected, so that the existing mountains are merely residual masses of the old volcanoes.

Extent and character of surface.—These rocks constitute the highest and most rugged peaks of the district. They form great amphitheaters, where steep cliffs and projecting buttresses are in strong contrast to extensive talus slopes formed by the débris of the rocks. In general, the rocks form sharply accentuated topographic features. In the gorge below Elkhorn they are cut by the creek in the narrow canyon with abrupt walls, seen in Pl. XLVII, *A*. Along Elkhorn and Crow creeks the rocks form the highest summits of the whole range.

Description.—The rocks show a wide range in mineral composition and texture, varying from quartz-diorite to diabase and from andesite-porphyries to tuffs, but are mostly typical andesitic rocks of various kinds. Owing to the reheating and metamorphism due to the proximity of the great granitic mass to the west, the original character of the rocks has been obscured, and their present texture and mineralogical composition are largely the result of such metamorphism. The most typical rocks are dense, dark colored, tough, and elastic. They vary from light gray to dark in color and from rocks devoid of phenocrysts to distinctly porphyritic forms, the latter being the most common. Despite the metamorphism to which they have been subjected, they still exhibit evidence of their original character as lava flows, breccias, tuffs, and intrusive sheets. They are dense, fine-grained rocks, with microcrystalline texture, and commonly show phenocrysts of white labradorite-feldspar, and more rarely of augite and hornblende. The determination of the predominant type as andesitic in habit is confirmed by the careful petrographic study made by Dr. Barrell, and a full description of them is given in the appendix.

Chemical composition.—The chemical composition of these rocks probably presents the same variations shown in their mineralogical character. But two analyses have been made: The first, that of the normal andesite; the second, that of the altered andesite.

Analyses of andesitic rocks.

Constituent.	E 35.	E 42.
SiO_2	54.50	59.64
Al_2O_3	17.97	16.64
Fe_2O_3	[a]8.55	2.33
FeO	(b)	4.35
MgO	3.37	2.10
CaO	9.36	4.59
Na_2O	2.34	3.31
K_2O	1.62	4.16
H_2O at 110° C	.14	.14
H_2O above 110° C	.96	.69
TiO_2	.94	1.08
CO_2	None.	None.
P_2O_5	.31	.49
S	[a].63	[c].01
Cr_2O_3	None.	None.
MnO	Trace.	Trace.
BaO	.06	.10
SrO	.05	.05
Li_2O	Trace.	Trace.
Total	100.80	99.68

[a] Contains both pyrite and pyrrhotite; amount undetermined, but between 1.59 Fe_7S_8 and 0 FeS_2, and 1.19 FeS_2 to 0 Fe_7S_8.

[b] FeO can not be directly determined. The 8.55 per cent Fe_2O_3, including Fe_2O_3, is equivalent of FeO and sulphides. FeO lies between 5.39 and 6.46, and Fe_2O_3 between 1.19 and 0.

[c] Undetermined whether sulphide or sulphate.

Weathering.—The andesite was traversed by a close system of fine joints that break on weathering into sharp and angular débris. On the highest and most rugged mountain slopes the individual blocks are several feet across and the slope exposures form rude stairways, while the solid rock forms rocky buttresses that extend beyond the general cliff wall or jut out from smooth talus slopes. In the exposures at lower elevations the solid rock forms broken cliff masses, as shown in Pl. XLVII, *A*, the network of closely spaced joints causing the rock to break on weathering into rather small fragments. In general the rock breaks into fine débris composed of pieces but a few inches across and forming great talus slopes which, where steep, are commonly bare of vegetation, but where flatter are covered by grass and a scattering growth of timber.

The rock is readily altered by ordinary weathering, the augite-biotite and other dark minerals changing to chloritic aggregates and the feldspars clouding from incipient kaolinization. This alteration is so widespread that it is impossible to procure specimens of the perfectly fresh rock. On the other hand, the final alteration of the rock results in merely a thin skin upon the surface of the fragments. The rock is very resistant and with the possible exception of quartzite offers more resistance to ordinary disintegrating agencies and to the wear and tear of stream transportation than any other rock known in the State.

DIORITE-PORPHYRY.

In the extreme southwest corner of the district there is a mass of fine-grained gray rock which is distinguished from the andesites with which it is associated by its more crystalline texture, spotted appearance, and uniformity of character. It is well exposed in the railroad cut at the mouth of Turnley Gulch, and also in the lower line in Queen Gulch. The exposure seen in the railroad loop at Turnley Gulch shows it to be intrusive in andesitic rocks. The rock is a diorite-porphyry of conspicuous appearance, owing to its markedly spotted or mottled character, which results from the presence of dark clusters of hornblende and biotite, which, with crystals of labradorite, lie in the fine-grained gray groundmass. The rock is uniform throughout the entire mass, the upper portion showing a slightly darker or bluish tint and resisting weathering better, so that the rock forms bold ledges. The upper 100 feet show distinct lamination planes parallel to the andesitic contact.

CHAPTER IV.

DESCRIPTION OF THE SEDIMENTARY ROCKS.

The stratified rocks cover a relatively small part of the district, and their normal characters have been in large part obliterated by the metamorphism they have undergone as a result of the heat and mineralizing action of the igneous masses which have broken through them. As already noted, the altered strata are, however, continuously traceable into the unaltered formations which make up the great folds forming the mountain ridges east of Elkhorn and extend to the valley of the Missouri River. Within the limits of the district it is difficult, if not impossible, to identify all the horizons recognizable in the unaltered area, and its importance did not justify the time necessary to trace out such connection. In general, the broader distinctions recognized in the unaltered series can be discriminated, while the Carboniferous limestone is identified by fossils in the immediate vicinity of the granite contact, and the overlying quartzites have been followed south to unaltered strata.

The rocks are all tilted, and the areas shown on the map include blocks broken off from the main body, though in general the masses are all part of the eastern flank of a broad fold composed of all the sedimentary strata from those of probable Algonkian age to the Cretaceous. The beds within the district are therefore not horizontal, but have a general eastward dip at angles of 30° to 55°. The general lack of fossils and the metamorphism of the rocks make the determination of their age almost impossible save by correlations and by tracing them out to the unaltered areas.

The sedimentary series at Elkhorn may be seen in an unaltered condition in the hills a half mile or more southeast of the town. The sequence there seen does not differ materially from that which prevails in the neighboring mountain ranges. A few notes upon the correlation of the formations are therefore given. The Algonkian beds are part of the Belt terrane, from which fragmentary fossil remains have been reported.[1] The Cambrian rocks of the neighboring ranges contain abundant fossils which prove their Middle Cambrian age, neither the Lower nor Upper Cambrian faunas being represented. The Silurian is commonly absent or represented by nonfossiliferous beds, the fossil collections from certain localities indicating Silurian tendencies. The Devonian is known by typical fossils from the dark Jefferson limestones of the Little Belt region and from the Three Forks shale of the Gallatin Valley. The Triassic is not recognizable. The extensive red sandstones which represent this age in Wyoming, occurring in the Yellowstone Park, though devoid of fossils, thin out and disappear northward, and have not been recognized within 100 miles of Elkhorn. The Jurassic, which, though sometimes less than 100 feet thick, is commonly exposed throughout the State and is almost everywhere fossiliferous, has not been positively identified in this district. The Cretaceous rocks of the State are commonly divisible into the usual well-marked groups. At some localities, however, the abundance of arenaceous beds makes lithologic distinctions impossible, and this and the absence of fossil remains at Elkhorn make subdivision or correlation of formations quite impossible. There can, however, be no doubt of the Cretaceous age of the beds when the section is compared with sections made in neighboring mountain ranges.

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[1] Pre-Cambrian fossiliferous terranes, by C. D. Walcott: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 199-244.

For purposes of mapping, the Elkhorn rocks have been divided into lithological units, mostly well defined and entitled to rank as formations, several of them corresponding to formations recognized in the unaltered rocks of neighboring districts. An attempt was made to measure a complete section embracing all the beds from oldest to youngest. There are, however, no continuous exposures, and the thicknesses herein adopted are estimates based upon such measurement as it was possible to make by pacing horizontal distances, all elevations being determined by aneroid and the results checked by the map. Several partial sections have also been used in making an average. In the folding and probable uplifting to which the strata have been subjected, as a result of dynamic activity before and during igneous intrusions, there has been some slipping along bedding planes, and certain shale formations are missing in the Elkhorn section.

Throughout the Paleozoic series the contrasting characters of successive beds permit the subdivision of the series even when the original characters are entirely destroyed. In the Mesozoic series, of which at least 2,000 feet exists in the district, notably on Crow Ridge, the rocks were originally impure shale and sandstones, grading into one another and seldom presenting sharply contrasted formations. These are now altered to tough, dark-colored, very dense hornstones, which so closely resemble one another that a classification in the field is almost impossible.

For the various reasons given, the age distinctions in the following table are only approximate, though the general characters and succession of the strata are evident.

Generalized section of the sedimentary rocks of the Elkhorn district, Montana.

Age.		No.	Name.	Feet.
Cretaceous		11	Crow Ridge beds: hornstones, adinoles, and quartzites; top capped by andesites of Crow Peak.	1,680
Carboniferous.	Neocarb.	10	Quadrant formation: sandstones and quartzites with interbedded limestones altered to a lime silicate hornfels.	380
	Eocarb.	9	Madison limestone: in places altered to marble.	1,900
Devonian?		8	Union shale: black shales and hornstone	130
Cambrian		7	Keene limestone: in part argillaceous	500
		6	Elkhorn hornstone	100
		5	Cemetery limestone: includes the white granular foot-wall limestone of the Elkhorn lode and the underlying blue limestones.	650
		4	Hobo Gulch shaly limestone: includes characteristic limestone flags.	153
		3	Starmount limestone: mostly argillaceous	600
		2	Alpreston quartzite: probable equivalent of Flathead quartzite.	125
Algonkian?		1	(*b*) Turnley quartzitic hornstone	200
			(*a*) Turnley shale: red sandy; indurated	200
			Basal beds concealed by andesitic lavas.	

ALGONKIAN ROCKS.

Turnley hornstones (*Spokane shale?*).—The Turnley beds are the oldest strata of the region. They occur only on the slopes above the Turnley placer in the southwestern part of the district, where they form a block separated from the main mass of stratified rocks by a tongue of granite. In color, composition, and relation to the overlying quartzite the rocks correspond to the red Spokane shale of the Belt terrane seen at Whitehall, 20 miles south, at Townsend to the east, and at Helena on the north. The lower, softer strata consist of rocks that weather to a good soil, forming open, grassy slopes. The overlying quartzitic hornstones are more resistant and their débris is conspicuous on the surface.

The lower division is 200 feet thick, and consists of shale metamorphosed to a very dense hornstone composed of light-brown biotite and quartz. A bed of impure iron ore 20 to 30 feet thick occurs in the middle lower part of the formation.

The quartzitic hornstones overlie the basal beds just noted and are 200 feet thick. The rocks, though well bedded, are very dense and hard and are of a gray-black color, so that they closely resemble the andesites. The texture is finely saccharoidal, the fracture conchoidal. The rocks are well exposed in a road cutting near the southern end of their outcrop. Microscopical examination shows the rock to consist of quartz and a small amount of olive-green mica.

CAMBRIAN ROCKS.

Alpreston quartzites (*Flathead quartzites*).—The quartzites are 125 feet thick, nearly white in color, and owing to their superior hardness are well exposed, forming the crest of the hill west of the town. The rock is an altered sandstone and is correlated with the Flathead sandstone, the base of the Cambrian series of the State.[1]

Starmount limestones.—These limestones are separated from the beds just described by an intrusion of granite-porphyry, but correspond in character and position to the Meagher limestone of the Little Belt section,[2] though positive identification is impossible and it seems best to give the formation a local name derived from that of a mine in it. The lowest beds consist of about 250 feet of light-gray, thinly bedded argillaceous limestone, which is rather soft and weathers down in even slopes beneath the first persistent limestone cliff of the sedimentary series. In the Elkhorn exposures the rocks are more or less metamorphosed and commonly altered to a light greenish-gray hornfels of great hardness. The upper member of the series, comprising 350 feet of rocks, differs from the lower chiefly in being more massively bedded and of a darker color, the rock being mottled with spots of a darker color and containing less silica and clay than the lower beds. The rocks resist weathering better than the underlying, more shaly strata, and form bluffs which are often conspicuous topographic features. Their best development in the Elkhorn district is on the hillside, south of the dams in which the mill tailings are caught (Pl. XLVII, *A*). At this place they are well exposed in the steep slopes above the railroad line. The largest exposure of the formation shows the strata to be separated from the underlying Turnley series by a quartz-diorite-porphyry intrusion several hundred feet in breadth, so that the exact relation of the two formations is nowhere absolutely determinable. If the correlation assumed be correct, the Starmount limestones must have been underlain by a considerable thickness of shale, corresponding to the Wolsey shale, but the intrusive mass of porphyry now found below the Starmount limestone was probably intruded also in the shale and now conceals it. In the southwestern part of the district a block of Starmount limestone has been overturned by an intrusion of andesite and now lies between the latter rock and a diorite-porphyry intrusion. This fragment is 400 feet in thickness, and has been altered throughout to an aggregate of garnet, augite, wollastonite, and feldspars. From a distance the rocks at this place still have the appearance and the structure of light-gray, massively bedded limestones, though on near view it is seen that the bedding planes have been entirely obliterated, and that the original stratified nature is recognizable only by slight changes in color or by differential weathering, which develops a thinly laminated structure on exposed surfaces. Similar altered rocks of the same age are seen in Alpreston Gulch, northwest of the town, and at Black Butte, where the rocks have been intensely altered and fragments occur in the gabbros. The description of these included fragments and remarks on their significance will come more properly in the account of contact phenomena given in the last chapter of this paper, to which reference must be made for details of their mineralogic characters.

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[1] See Geology of the Little Belt Mountains, by W. H. Weed: Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, pp. 284–287, for discussion of the Cambrian formations and their relations to the rocks of other ages.

[2] Weed: loc. cit., p. 285.

Hobo Gulch lime-shale.—This name is applied to a well-marked group of strata seen in the railroad cuts near the tailing dams and in Queen Gulch. It is an important horizon for mapping, as it possesses easily recognizable characters and separates two thick and somewhat different limestone formations.

The lowest member of the series consists of 18 feet of shales which have no conspicuously marked characteristic. A limestone nearly 100 feet in thickness succeeds the shale. The rock is nearly black, with abundant smooth joint planes. On weathering it forms angular, smooth, dark débris by which the horizon may frequently be traced. The uppermost part of the formation is the "crinkled limestone," a 35-foot bed of banded cherty limestone, thinly bedded, and with the cherty material in the form of lenses averaging two-thirds of an inch in thickness and 1 or 2 inches in length. This is the most characteristic bed of the Cambrian series wherever it has been observed in Montana, and commonly consists of pure limestone with lenses of cherty material. The crinkled appearance is not due, as might be supposed from the Elkhorn exposures alone, to a bending of these rocks, in which the limestone would be curved about the harder siliceous lenses, as this characteristic has been noted where the beds are perfectly horizontal and show no folding whatever. In weathering, the limestone is more readily attacked and as a consequence the impure, cherty, or argillaceous lenses weather in relief and the bowlders present a rough surface with lozenge-shaped depressions. These limestones are so much harder than the strata adjacent to them that the horizon is readily distinguishable despite its small thickness and the fact that it does not present any marked topographic relief. The underlying Starmount limestones often show the same crinkled appearance, so that in identifying the horizon it is necessary to look for the underlying shale. This formation seems to correspond fairly well in position to that of the Pilgrim limestone of the eastern Montana Cambrian exposures, in which case the basal shale would be the Park shale horizon. This correlation is, however, not based upon anything more than lithological sequence.

Cemetery limestone.—This limestone, named from its occurrence at the Elkhorn cemetery, consists of 650 feet of beds, all of which are true limestones. The lower 70 feet consist of blue limestones, followed by 50 feet of dark-blue granular limestone, weathering with a lighter-gray surface and showing sections of brachiopods and crinoid stems. Above this occurs a great thickness of light-blue, thin- to thick-bedded limestone, sometimes mottled with dark-blue spots in a lighter ground. In Queen Gulch the lower beds are somewhat altered by contact metamorphism and show a decidedly crystalline texture. The same also is true of the rocks exposed in the hillside west of the Elkhorn mill, where the rocks are very dark and crystalline and break into small blocks whose dark color presents somewhat the appearance of a basic eruptive when seen from a distance. It seems hardly possible that this dark color can be due to contact metamorphism, inasmuch as the tendency of heat would be to drive off the organic material to which this color is due. This being true, it is hard to explain a decided difference in the appearance of the rocks near the Elkhorn mill and those in Queen Gulch, unless the latter is really the lower limestone of the Hobo Gulch formation. The uppermost 100 feet of the Cemetery limestone includes the thin- and thick-bedded white or light-gray limestones, showing a crystalline, granular texture. This bed varies to a straw-yellow dolomitic marble, which constitutes the foot wall of the Elkhorn mine. It may be seen on the surface in Queen Gulch and in the railroad cut east of the town.

Elkhorn hornstone.—The Elkhorn hornstone is seldom seen in good surface exposures, but its location has been determined by numerous prospect pits made to trace out the bedding plane between it and the underlying limestone, the horizon on which the ore bodies of the Elkhorn mine occur. The rock is well exposed in a hanging-wall crosscut of the Elkhorn mine, consisting of a series of thin-bedded strata, varying in composition from nearly pure, extremely dense, and fine-grained quartzites to calcareous and argillaceous shales. The rocks are indurated and metamorphosed and in the mine are really hornstones. The thickness is estimated at 40 feet, though in the mine a crosscut 120 feet long is driven through these and closely similar calcareous rocks which dip east at 40°.

SILURO-DEVONIAN ROCKS.

Keene limestone.—This formation consists of limestone beds which are so poorly exposed, owing to a covering of morainal and other débris, that their thickness is not accurately known, but is estimated at 500 feet. The basal beds consist of bluish-gray limestone, usually altered to a fine-grained marble. The upper strata are more thickly bedded and lighter in color. The formation is, as a whole, slightly arenaceous and, though devoid of fossil remains, is believed to include the uppermost or Yogo limestone of the Cambrian series and the overlying dark-colored granular Jefferson limestones of Devonian age.

Union shale.—This readily recognizable horizon comprises a basal bed of black shale 30 feet thick, overlain by a metamorphosed siliceous limestone that is about 100 feet thick. The latter rock is altered to a light-colored jaspery material that weathers in smooth-surfaced, angular blocks, whose outcrop sometimes forms low ridges. The formation, like that below it, is broken by igneous intrusions, and no continuous exposures occur. It is seen in numerous prospect holes and may commonly be recognized by the dual character. The best exposures are three-fourths of a mile north of the town, where the shale has been fruitlessly prospected for coal.

Near the igneous rocks the formation is so altered as to be unrecognizable by its lithological character alone. Near the Union mine, at the head of Alpreston Gulch, it is altered to a light-colored rock. In Queen Gulch, near the Cemetery Ridge diorite stock, the shale is altered to dark purplish-red hornstone, while the overlying siliceous limestone is an exceedingly hard, light-gray hornstone, much fractured by minute jointing. The horizon corresponds to the Three Forks shale, a Devonian horizon.

CARBONIFEROUS ROCKS.

Madison limestone.—The great limestone series known as the "Madison formation" is conspicuous in the Elkhorn district, as it is elsewhere in the State of Montana. A conservative estimate of the total thickness in the Elkhorn region is 1,900 feet. The rocks consist here, as elsewhere, of limestones which in the lower half of the formation are dark colored and sometimes argillaceous, though usually the dark color is due to carbonaceous material. The middle portion of the series consists of very pure limestones, which are very resistant to weathering and usually form white cliffs that are conspicuous features of the landscape. In this district, however, the limestones have been recrystallized into marbles, and as a consequence of their very coarse texture and friable nature weather somewhat readily, and hence do not form very striking exposures. The best section is found on Crow Ridge, northeast of the town of Elkhorn. The series contains fossil remains, even in the marbleized areas, and these show the usual Lower Carboniferous forms common to the formation throughout the State. The following section has been made by Dr. Barrell:

Section of the Madison limestone on Crow Ridge

		Thickness in feet.
9.	Somewhat siliceous limestone	170
8.	Light-colored andesitic sheet	1
7.	Concealed limestones	225
6.	Light-blue limestone with dark-blue circular spots	7
5.	Pale-blue limestone with white seams and small crinoid stems	370
4.	Pale-blue massive limestone, forming at this point the lowest prominent outcrop	148
3.	Blue limestone with thin cherty seams	715
2.	Blue limestones, somewhat banded, with large crinoid stems and white chert bands prominent on weathered surfaces	66
1.	Blue limestones containing near the middle, at this point, beds holding abundant needle-like crystals of tremolite	200
	Total	1,902

A section made by the writer in the hills east of Elkhorn Creek, a few miles below the town, where the beds are unaltered, shows that the rocks are similar in character, and as the section goes up into the quartzite of the Quadrant formation and includes the red shales, which seem to be lacking in the section as exposed on Crow Ridge, it is given in detail:

Section of the Carboniferous strata exposed in the hills east of Elkhorn Creek, 3 miles below the town.

		Thickness in feet.
23.	Quartzite, rather coarse grained, dark colored on weathering, and very resistant	10
22.	Limestone, light gray in color, the outcrop forming a massive ledge	5
21.	Sandstone, impure and shaly, reddish in color	5
20.	Quartzite, gray, dense, outcrop marked by trees	15
19.	Limestone, gray, thinly and irregularly bedded, cherty	4
18.	Quartzite in heavy beds varying in color and texture; the rock often shows smooth jointing and the weathered surface is knotted	35
	Quadrant formation:	
17.	In exposure a soil shows sandy clays of reddish or brown color	15
16.	Limestone, gray and impure, and forming part of a clay-shale series	1
15.	Shale, red and purple	6
	Igneous intrusion of basic augitic rock, much decomposed	5
14.	Quartzite, white to buff in color, and occasionally pink	3
13.	Limestone shale, grading into limestone at base, thin laminæ of limy material alternating with arenaceous material	8
12.	Limestone, light gray in color; weathers with rough surfaces, jointed, and showing masonry-like outcrop	4
11.	Shale of buff to pink color; laminæ from one-third to one-eighth of an inch thick; color possibly due to igneous intrusion beneath it	3
	Igneous intrusion of augitic rock	6
10.	Limestone, the upper 4 feet forming a ledge outcrop	12

	Thickness in feet.
9. Impure limestone, in part red and dolomitic, and carrying sand	30
8. Red limestones, the color due to blotches and included masses of reddish material in gray or buff limestone	10
7. Limestone, forming rough ledge of pink-gray color with knotty and somewhat open-textured outcrop	10
6. Sandstone, red and arenaceous, weathering into red clays, good exposures being rare	60
Madison limestone:	
5. Limestone, gray, cherty, brecciated	10
4. Limestone, gray, thinly bedded (1½ to 3 feet), of a slaty or blue color, carrying abundant chert fragments with seal-brown surface	30
3. Limestones of typical Madison aspect, rather thickly bedded, showing blocky fracture and carrying large, irregular-shaped fragments of chert; the upper portion somewhat thinly bedded	255
2. Limestone, very massive, without traces of bedding, the upper 30 feet of dark-blue or gray, very dense, cherty limestone, emitting a fetid odor when struck with a hammer	80
1. Limestone, dark gray, weathering to a buff gray, and with a peculiarly guttered surface; carries occasionally black cherty masses of ovoid shape and shows *Zaphrentis*, crinoid stems, and corals	80

Quadrant formation.—The Quadrant formation corresponds closely in its stratigraphic relations and lithologic composition to the rocks known by this name elsewhere. Owing to the intense alteration to which the rocks have been subjected in Crow Ridge, the formation consists there of quartzite and hornfels; but if the same series be studied at the head of Queen Gulch, the rocks will be found unaltered. The sequence and character of the basal beds are given in the sections on the preceding page. The Crow Ridge section, which is given below, was measured by Dr. Barrell, and shows a thickness of 380 feet between the Madison limestones and the Cretaceous rocks.

Section of Carboniferous sedimentary strata (Quadrant formation) exposed on Crow Ridge northeast of Elkhorn.

	Thickness in feet.
6. Alternating pure and calcareous quartzites, just beneath the lowest Mesozoic quartzite	75
5. Quartzitic hornfels	20
4. Light-gray quartzite	7
3. Lime-silicate hornfels	20
2. Light-gray reef of lustrous quartzite	20
1. Banded strata of light-colored lime-silicate hornfels, ranging from nearly pure limestones to nearly pure quartzites, the base of the series	240
Total	382

MESOZOIC ROCKS.

Crow Ridge series.—Under this heading all the Mesozoic strata have been grouped, as, owing to the absence of well-defined lithologic units or of fossil remains, it has been impossible to differentiate the Juratrias or the groups composing the Cretaceous series. The only exposures of the formation which lie within the district are those of highly metamorphosed rocks. Their original character was unquestionably that of the impure limestones, shales, and sandstones which characterize the formations of this age in other parts of the State, and which may be seen well exposed a few miles east of Elkhorn. At present, however, the rocks consist of hornfels, adinole, and quartzite, and show very intense alteration. The rocks are exposed in the amphitheater south of Elkhorn Peak and in the upper gorge of Elkhorn Creek, where they dip steeply to the east, and the ledges may be seen running down the slopes.

The Crow Ridge series is best exposed on the southwest spur of Crow Peak, to which the name Crow Ridge is applied. The rocks consist near the andesite capping of light-cream, green, pink, and lavender hornfels and adinoles, alternating with steel-gray to pink quartzites. One bed of quartzite forms the narrow, even crest for one-half to three-fourths of a mile, the strike being N. 40° W. and the dip 20° E. A measured section was made of the rocks exposed on Crow Ridge, but the uppermost beds being capped by andesite the total thickness of the series is not known. The following section shows the thickness and character of the series.

Measured section of Mesozoic strata exposed on Crow Ridge, northeast of Elkhorn, Mont.

		Thickness in feet.
	Andesitic lava flows, with tuffs and breccias at the bottom, lying upon an erosion surface of Mesozoic, terminate the series.	
	Mixed sediments, lime and clay predominating:	
30.	Lime-clay-silica banded hornfels with mottling due to segregations	180
29.	Fine-grained dark shales with platy parting	260
	Mixed hornstones and quartzites:	
28.	Dark mottled lime-clay-silica hornfels	35
27.	Dark granular sandstone consisting of a water-sorted arkose and what may be a devitrified volcanic glass sand	40
26.	Light-colored lime-clay-silica mottled hornfels	60
25.	Light-gray medium-grained sandstone	110
24.	Dark limestone, rather impure	48
23.	Calcareous quartzite	12
22.	Light-colored lime-silica hornfels	40
21.	Intrusive sheet of light-colored andesitic porphyry	3
20.	Dark-blue hornstone	22
19.	Thinly laminated quartzite	12
18.	Pure, lustrous quartzite	15
17.	Light-colored lime-silica hornfels	60
16.	Somewhat mottled lime-silica hornfels	12
15.	Coarsely granular quartzite	6
14.	Light-colored lime-silica hornfels	45
13.	Dark and conspicuously mottled hornfels	4
12.	Medium-colored lime-silica mottled hornfels	8
11.	Light-gray lime-silica hornfels	22

		Thickness in feet.
	Granular sandstones:	
10.	Light-gray, cross-bedded, granular sandstone, the grains consisting of what is probably a devitrified volcanic glass	50
9.	Similar to above, but bluish gray in color	37
	Limestone and hornfels:	
8.	Bluish-gray limestones with well-developed cleavage and many rust-colored hornfels bands	60
7.	Light-gray hornfels with many rust-colored bands	15
6.	Bluish-black limestones with well-developed cleavage	8
5.	Bluish hornfels, predominantly lime, with abundant white to rust-colored siliceous segregations	10
	Quartzite series:	
4.	Siliceous hornfels, somewhat banded, topographically prominent	150
3.	Coarsely granular quartzite, with some impurities	65
2.	Lime-silica hornfels, mottled with mineral segregations	20
1.	White, rather massive quartzite, topographically prominent	275
	Total	1,680

The petrographic nature of these altered rocks is fully described in the petrographic appendix to this report, and need not be further mentioned here.

CHAPTER V.

RELATIONS OF ROCK MASSES.

Under this head it is proposed to give a brief account of the relations of the rock masses to one another, including the probable manner of intrusion of the igneous rocks and their relative age. The rocks themselves have been described in preceding chapters; in this place a résumé is given of all the known facts concerning the dynamic geology of the region, with such conclusions as seem to be justified by the facts.

The surface distribution and areal extent of the different rock masses are shown on the geological map (Pl. XLV). The map does not, of course, give the known vertical relations of such masses, except in so far as they are expressed by the positions of the boundary lines in relation to the contours of the surface. The accompanying plates of cross sections (Pls. XLVIII and XLIX) represent vertical sections across the district along lines shown on the areal map, being designated by the same letters on lines and sections. The profile of each section is drawn from the contour lines of the topographic map, and the geologic boundaries correspond to those of the geological map. The size, shape, and relation of the rock masses shown on the sections, though based upon all the known facts, are largely ideal, and it is evident that this must be so, inasmuch as despite the marked ruggedness of the district the natural exposures embrace ordinarily less than 1,000 feet of vertical distance, and between Elkhorn Peak and the lowest point in the district the vertical distance is but 3,400 feet.

SEDIMENTARY FOUNDATION OF THE DISTRICT.

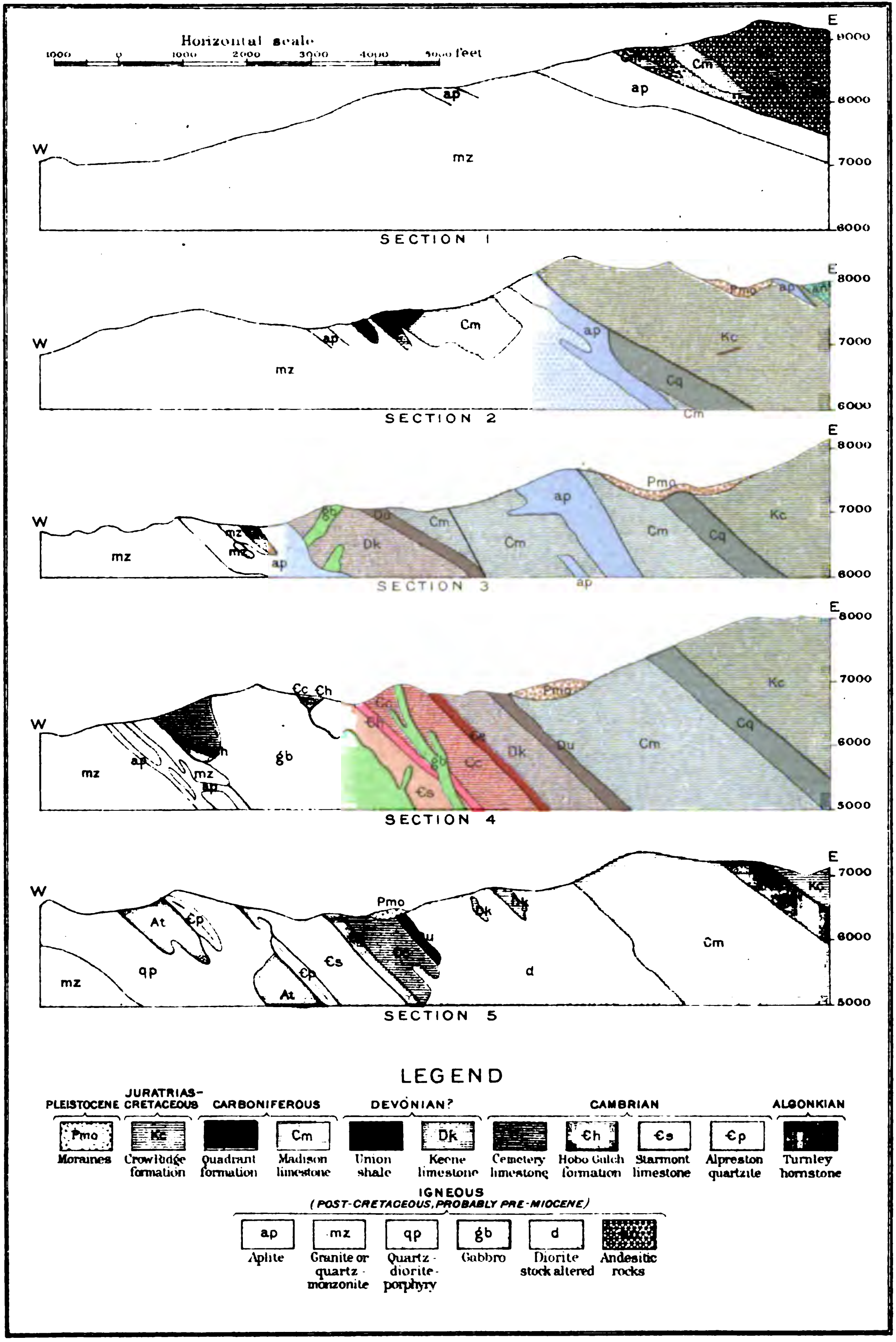
The sedimentary beds all lie at steep angles and have a prevailingly northward dip. The sinuosities of outcrop, as shown on the areal map, are largely due to topographic relief, since the strike is very uniform, being approximately north and south. The rocks are traceable into the beds forming the big fold east of Elkhorn Creek a few miles below the town, where the anticline is seen to be but one of the lesser folds of an extensive area in which the rocks form long anticlines with intervening synclines, and in which topographic relief and geological structure in general coincide very closely. The block of sediments at Elkhorn forms the eastern limb of an anticlinal fold, the western limb and crest of the fold having formerly existed in the area now occupied by the granite. The axis of this anticline pitched southward. Of the western limb of the fold nothing definite is known, though it may be conjectured to have been steep and likely to develop into a fault yielding readily to the disrupting force of igneous intrusions.

While the original structure of the sediments resulting from orogenic movements which preceded igneous intrusion was that of a simple arch, the folding of the rocks developed many lesser crumplings of the beds, and these creasings and crinkles, with accompanying slips and small faults, and crushing of the rocks of the big fold, were naturally most marked in the beds which formed the core of the arch. Such a minor fold is shown on the map 1,500 feet north of the shaft house of the Elkhorn mine by a marked bend in the outcrop; this little fold develops into a fault west of Alpreston Gulch. In the Cemetery limestone this fold sheared the rock and developed lines of fracture which were followed by the dike-like intrusions of gabbro, while the fault into which the fold developed determined the southern limit of the gabbro stock. Other minor crumplings occur, but the two just mentioned are the principal ones, because they influenced, if they did not determine, the position of the igneous intrusion with which the ore bodies are genetically connected.

GABBRO STOCK OF BLACK BUTTE.

The gabbro stock is believed to be the oldest igneous mass of the district. As shown by the areal distribution of the rock, it occurs in detached masses, with many small bosses and rounded intrusions breaking up through the sedimentary rocks that surround the main bodies, which are shown in the structure sections, Pls. XLVIII and XLIX, to be parts of one great body. The occurrence of the smaller intrusions, as well as arms of the larger masses, along northeast-southwest lines indicates that lines of fracture in the sedimentary rock were followed by the intrusion, though it is evident that the latter rocks were extensively shattered at the time of the intrusion. From these and other details of occurrence observed in the field, it is inferred that the gabbro underlies a large part of the region drained by Alpreston Creek and that the various exposed masses are all parts of one deep-seated mass, from which the stocks and pipes now seen rise upward like branches from the trunk of a tree.

The rocks adjacent to the exposed stocks show very great alteration—in fact, but little less than that of the included fragments seen in the rock. The strata about the Black Butte stock dip toward it from all sides, indicating a settling in of the crust upon the partially cooled and consequently contracted magma. This, however, is not a satisfactory explanation of the broken condition of the sediments south



CROSS SECTIONS OF THE ELKHORN DISTRICT
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of Black Butte, where occur several small intrusions that are not shown on the geological map owing to their limited extent, nor of the conditions seen upon the west slope of Black Butte, where the gabbro holds so many fragments that in places more than one-fourth of the mass is composed of them. Such occurrences seem clearly to indicate the taking up of shattered or brecciated material resulting from the fracturing that opened a way for the intrusion.

Both the alteration of the sediments and the coarse grain of the gabbro indicate prolonged and intense heating, followed by slow cooling. It should be noted, however, that the granitic rocks caused a later reheating and alteration of this same area, and that the effects of thermal metamorphism now observable may be largely the result of such later action. It is certain that the gabbro is later in age than any of the sedimentary rocks, since it cut across the folded beds whose folding was later than the time of deposition of the Cretaceous beds of the district, a period certainly not earlier than Middle Cretaceous nor later than the Laramie.

The gabbro is known to be the oldest igneous rock because fragments of it torn off by the force of the later intrusions occur in the other igneous rocks. The western side of the Black Butte stock is sharply truncated by the granitic batholith, and it is impossible to tell what the former extent of the gabbro may have been. The chemical composition of the rock might suggest that it was a vent from which andesitic lavas were ejected, but this is not supported by the evidence. In fact, there is reason to believe that the entire mass was formerly covered by sediments, now largely worn away, and that no outlet to the surface ever existed. The intense alteration of adjacent rocks and the coarse grain of the gabbro certainly accord with this hypothesis and with the evidence that slow cooling of the mass took place.

DIORITE STOCK OF CEMETERY RIDGE.

In its relations to the sedimentary rocks the diorite stock southeast of the town differs markedly from the gabbro stock just noted. The extremely irregular contact seen on the map shows that the rock has broken up through the limestones and entirely replaced large masses of them. It is therefore remarkable to find isolated patches of Keene limestone lying upon the diorite and to observe a block of Elkhorn shale extending up the ridge far out over the diorite, yet maintaining its original position. Field observations show that this mass and the patches of Keene limestone are merely cappings over the diorite. It is apparent that they are parts of a cover of sediments now nearly removed by erosion. The presence of the Union shale within the diorite suggests that it was able to resist the corrosive action of the molten rock better than the limestone. Between the Elkhorn argillite on the west and the massive limestones forming the eastern wall of the intrusion at least 600 feet of limestone is missing, showing that the intrusion not only forced apart the strata, but caused the removal of great quantities of limestone. It is certain, from the observed facts, that the intrusion must have been a very quiet one, scarcely disturbing the overlying sediments; yet the removal of a great mass of the Madison limestone would indicate violent rupturing of the rocks. The replacement of so large an amount can be accounted for in various ways. (1) It may have been floated upward or been ejected from a volcanic vent. This suggestion is negatived by the positive evidence that the intrusion was covered by a sedimentary cap subsequently removed by erosion, and therefore there was no room for the floating of the blocks and no possibility of ejection. (2) The limestones, etc., that formerly occupied the place now held by the diorite may have been fractured by the force of the intrusion, and the blocks sunk down through the liquid magma into the reservoir from which the igneous matter came. (3) The limestone may have been assimilated and dissolved by the molten rock. The latter hypothesis is one for which absolute proof is necessary, as it is opposed to the observations made by scores of geologists the world over. Though the petrographic study of the rocks shows no proof of this, the facts observed here seem to indicate some such action—viz, the apparent corrosion or eating into the limestone by the diorite, the lack of disturbance of the strata, and, lastly, the very uneven, stringy, or smeary nature of the diorite itself, which, as is shown in the petrographic appendix, varies from shonkinite to quartz-diorite, and which in the field is seen to vary from place to place.

DIORITE-PORPHYRY LACCOLITH OF QUEEN GULCH.

The massive diorite-porphyry seen at the junction of Turnley, Queen, and Elkhorn gulches constitutes an intrusion which is laccolithic in character. The bottom of the mass rests upon altered sediments (Starmount hornfels) and andesitic rock, the contact plane dipping SW. at 42°. The exposure seen along the railroad loop shows that the intrusion domes up the andesites, the upper contact at this place dipping SW. at 25°. The andesitic cover has been largely removed by erosion, but enough is left to show clearly that the mass constitutes an inclined laccolith intrusive in andesitic rocks. Sections 6 and 8 of Pl. XLIX cross the laccolith at unfavorable places, so that the laccolithic structure is not well shown in them. The laccolith rock is clearly younger than the andesites, but as it does not come in contact with any of the other igneous rocks of the district no further statement as to its age can be made, though it might be inferred from the composition and mineralogic character that the rock formed a part of the general andesitic eruptions, and was therefore older than the quartz-diorite and the granitic rocks.

TURNLEY RIDGE QUARTZ-DIORITE-PORPHYRY STOCK.

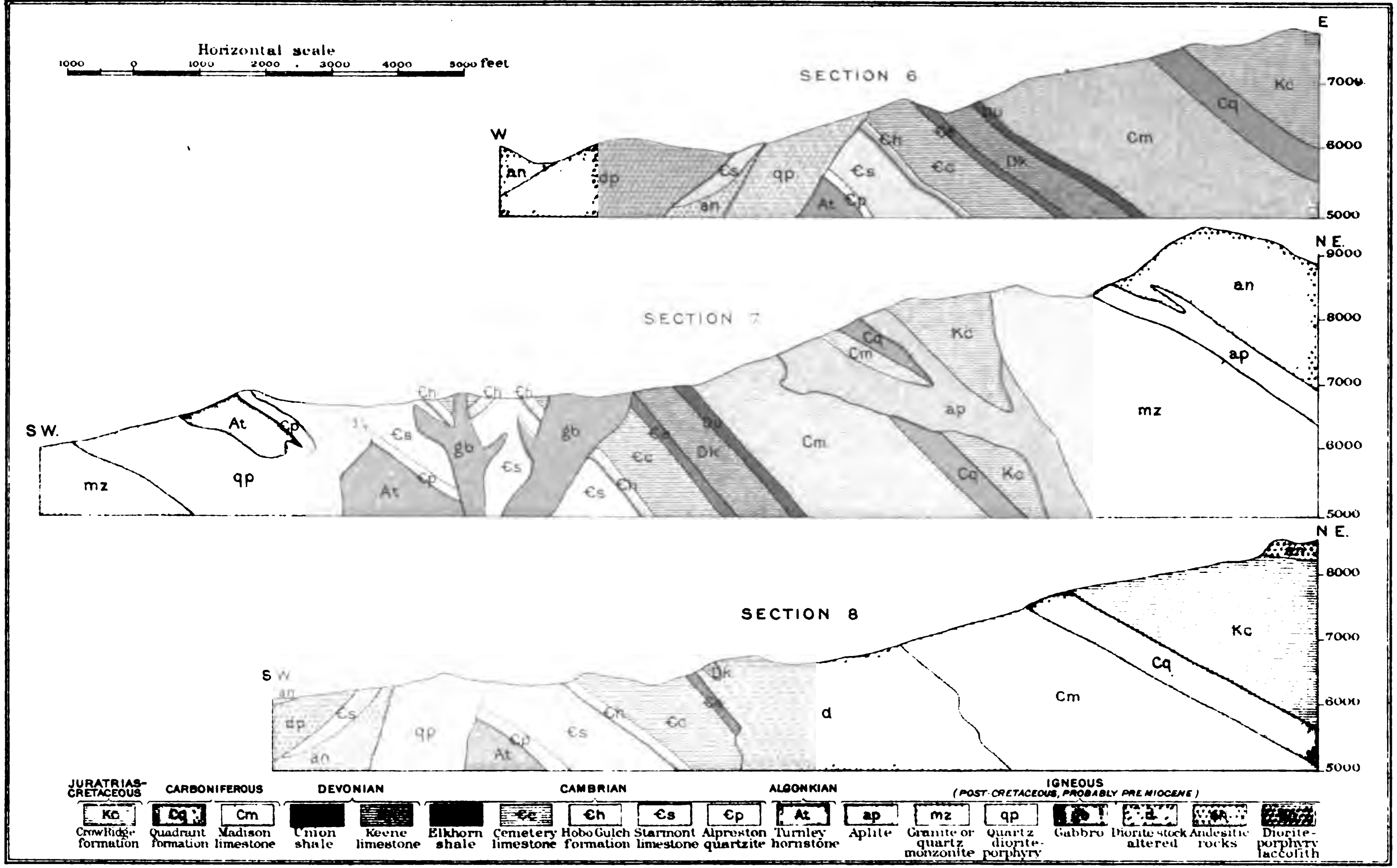
This rock forms a very irregular intrusion, breaking up through the oldest sedimentary strata and through the andesitic rocks at the junction of Queen and Elkhorn creeks. The mass is clearly intrusive, as is shown both by its field relations and by the contact chilling of the rock and the fragments of older formations which it carries. The intrusion itself is cut by the granite (quartz-monzonite), and the metamorphic effects due to the quartz-diorite-porphyry can not be satisfactorily distinguished owing to the great heat due to the later intrusion. The mass is deeply dissected by the gorge of Elkhorn Creek, and good exposures are common, though rock débris covers large parts of the area. The location and shape of the intrusion are believed to be due to the presence of Algonkian and Cambrian shales. These rocks, which are easily invaded by igneous magmas, owing to their weak resistance, are commonly the site for intrusive rocks in many districts in the State. It is true that these formations as now seen at Elkhorn are tough and resistant, but this character is the result of the metamorphism effected by the igneous magma itself or by later intrusions. It will be observed that the shape of the intrusion, as shown on the map, corresponds in a general way with the strike of the sedimentary rocks. The actual contact, however, is quite uneven, tongues of the porphyry invading the easily ruptured sediments and sending out wedge-shaped masses and sheets which split apart the strata. The southern end of the intrusive mass has a dike-like arm but a few feet wide which cuts across the sediments and is well exposed in Queen Gulch. To the north the mass is a mile wide and is bounded by a variety of rocks, into all of which, except the granite, it sends out intrusive arms. The granite is clearly later than this rock and cuts it. The map, Pl. XLV, and sections 5, 6, 7, and 8 of Pl. XLVIII show the relation of this mass to the adjacent rocks. It will be observed that the intrusion as drawn on the sections is assumed to widen out toward the surface. This is inferred from the fact that the rock has split apart the strata and sent out wedges into the rocks on every side, and this it could more readily do if the intrusion was somewhat funnel shaped, broadening at the top. The included mass of sediments shown in sections 5 and 7 of Pls. XLVIII and XLIX corresponds very closely in orientation to the masses lying to the north of the intrusion. These rocks, which are essentially quartzitic, probably extended northward and connected with a larger mass in the area now occupied by the granite. The writer does not believe that the evidence warrants the assumption that this large block of sediments has been torn loose and floated into its present position—a position so closely corresponding to the original one occupied by the sediments before the invasion of the porphyry.

The relative age of the rock is determined by very satisfactory evidence. At the contact with the andesite, where an apophysis of porphyry projects into the latter, the rock shows a distinct chill texture, visible to the eye and unmistakable when the rock is seen in thin section under the microscope. On the hill crest, 3,000 feet west of the town, the porphyry includes two masses of gabbro-diorite which, though too small to have produced any chilling of the porphyry, are themselves slightly metamorphosed. As these inclusions have a small slab of the Starmount hornfels attached to them, an association common in their original position, it seems clear that they are fragments broken loose from the main gabbro mass. The relations of the porphyry to the quartz-monzonite are also clear. The contact line is sharp and a careful search of the granite reveals occasional masses of quartz-porphyry but a few inches in diameter inclosed in the granite. It is therefore certain that the porphyry is an earlier intrusion and not merely a dike-like extension of the granite mass. The conclusion is reached, therefore, that the quartz-diorite-porphyry was the latest intrusion preceding the great welling forth of the granite.

ANDESITIC MASSES OF ELKHORN PEAK, QUEEN GULCH, AND ELKHORN GULCH.

Andesite.—Although great quantities of andesitic rocks exist in the district and form mountain masses for many miles about it, the rocks are almost entirely extravasated lavas. At Elkhorn Peak and at Turnley Gulch intrusive rocks occur, but the rocks do not constitute masses filling the conduits from which the breccias may be supposed to have come, but are later rocks cutting the breccias, though of the same general character and period of eruption. The source of most of these andesitic rocks must have been some point or points west of the district in the region now occupied by the Boulder batholith, the small size of the fragments composing the breccias and the easterly dip of the beds pointing to a source at least several miles westward. On the other hand, the extensive bodies of intrusive andesitic rocks carrying such enormous blocks of limestone as that now forming the marble cliff of Elkhorn Peak (XLVII, *B*) indicate a source of supply close at hand.

That the andesites formerly covered a large part if not all of the district seems probable from the occurrence of these rocks in Queen Gulch, at a low elevation, and in the gorge of Elkhorn Creek below the mouth of Queen Creek. The physiography of the region shows that it has been extensively faulted since the granite batholith was formed, but despite this the evidence seems clear that the andesitic rocks were thrown out by volcanic eruptions of great magnitude, and fell upon and covered a region consisting of highly folded sediments carved into a country nearly as rugged as that seen to-day. There seems no alternative but to accept the conclusion that these rocks cov-



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ered the district to a considerable depth, the surface sloping rapidly toward the southeast. Despite the enduring character of the rock and the fact that the highest peaks are now formed of it largely because of this character, it is true that it wastes and is removed by stream and frost very rapidly, and enormous masses of it must have been removed and carried down into the valley of the Jefferson River during the long period that has intervened since the formation of the rocks.

Marble cliffs.—The andesitic rocks of Elkhorn Peak consist in part of indurated metamorphosed fragmental rocks—volcanic breccias and tuffs—forming its summit and the crest westward, and of underlying massive intrusive rocks, which sometimes occur as sheets between the altered breccias and constitute the great mass of Elkhorn Peak. The latter rocks have apparently been intruded during the activity of the andesite volcano, being injected between the sedimentary platform and the overlying fragmental material making the former volcanic cone. A measure of the magnitude of the intrusion just mentioned and of its force is afforded by the inclusions of altered limestone found within it. These inclusions are clearly blocks torn off from the underlying Madison limestone and borne into their present position by the force of the ascending magma. The largest block is well exposed on the western flank of Elkhorn Peak and in the white cliffs which are so conspicuous a feature of the peak, and look like a bank of snow when seen from the south. These cliffs are shown in Pl. XLVII, *B*, which has been made from a photograph taken on the shores of a lakelet that fills a hollow in the amphitheater bottom. Beneath the white marble cliffs the dark andesite is seen, with a second or lower stratum of white marble beneath it. The view shows the dark-colored andesitic rocks projecting above the snow bank that overlies the marble cliffs. The higher slopes seen on the right-hand side of the view are also andesite, but the line of cliffs beneath them consists of hornstones belonging to the Mesozoic or Crow Ridge series, with a tongue of aplitic granite beneath them. The rock composing the white cliffs is a very coarsely granular and glistening marble whose individual grains are oftentimes an inch across. The mass is 125 feet or more thick in the cliff, and may be traced across the gently sloping shoulder of Elkhorn Peak for a distance of 3,000 feet. The lower marble mass seen in the view is in some places 50 feet thick, and is also traceable across the north side of the peak for a distance of not less than 2,000 feet, though it is in part concealed by débris, and its northward extension is inferred from the presence of occasional blocks of limestone and from exposures afforded by several prospect pits. This lower mass of marble is cut by stringers and dikelets of andesite. Its eastern end is abruptly truncated by the andesite, and westward it gradually wedges out, as shown on the map. The rock, though in the main a pure marble, contains two bands of white hornstone, one 3 feet and the other 3 inches in thickness. These hornstones are clearly an alteration product of interbedded layers of impure limestone, and therefore show the original stratification planes of the rock. They dip NE. at 18°. To the southwest the lower block of marble rests upon aplitic granite, which has been intruded between it and the andesite, the latter rock elsewhere underlying it. The upper and larger block of marble also shows by a band of impure limestone that the dip of the strata is slightly greater than the dip of the underlying mass. It appears probable that these two blocks were formerly united and have been wedged apart by the intrusion of andesite, the relative position of the blocks indicating that the wedge entered from the west. The isolation of these blocks at an altitude of several thousand feet above the Madison limestone and so near the Mesozoic beds shown in the plate indicates either that very profound faulting has occurred, or that these blocks have been torn from some deep-seated mass and floated into their present position in the liquid andesite inclusion. Direct upward movement is improbable in view of the wedging apart of the blocks from the west. The more reasonable hypothesis—and one supported by the occurrence of many smaller included blocks of marble seen in the cliffs to the east—is that a great flood of andesitic magma welled up from some vent to the westward, lifted the overlying breccias, and intruded itself between them and the Mesozoic shales.

In summary, the facts already presented show that the andesites rest upon sedimentary rocks of greatly varying age and that the contact occurs at widely different elevations. It is inferred from this that the breccias and lava flows composed of these rocks covered a very rugged area of sedimentary strata. The breccias show a rude bedding dipping eastward on Crow and Elkhorn peaks and southward in the mountain mass southwest of Elkhorn. These relations indicate that the source of the material lay somewhere to the west of the Elkhorn district, and from the character of the beds there seems reason to believe that the masses now seen are the residual parts of a great volcanic pile whose center lay some miles to the west of Elkhorn. Direct evidence of this has been removed as a result of the granite intrusion, with later uplift by faulting and subsequent erosion, but parts of the western slope of the former andesitic volcanic cone may be well seen west of Boulder Valley.

GRANITIC BATHOLITH.

As noted in the introductory chapter, the Elkhorn district includes the border of a great granite area extending for many miles to the west of Elkhorn, and reaching from the vicinity of Helena to the Highland Mountains south of Butte. This great mass of granite is all one connected mass and has been named the "Boulder batholith."

On the reconnaissance map that shows the relations of the Butte district to the surrounding region this batholith has been outlined and its relations have been studied. At a number of points throughout the granite region this rock is covered by andesitic rocks which were at first thought to be more recent than the granite, lying as they do upon it. Isolated masses occur at scattered localities, and in each case the relation seems to be the same. Notwithstanding the altered character of the andesites, which quite clearly showed the intrusion and metamorphism of the fragmental forms, no positive evidence was developed in the central part of the area of a more recent age of the granite. Later studies, however, at Elkhorn, at Pipestone Hot Springs, and at a point midway between these two localities, showed conclusively that the andesite is older than the granite, as fragments of it are included in the granite mass near its borders. Abundant evidence that the aplite is later than the andesitic rocks was found at Elkhorn. The specimen figured in Pl. LXII, *B*, shows this relation, as a minute stringer of aplite is seen penetrating the fractured andesite. These facts, together with the metamorphosed condition of the breccias seen upon the granite, show that the andesites are in part, at least, the remnants of a former cover to the granite batholith, the latter having broken up through an extensive area of andesitic rocks, the heat of the intrusion producing a metamorphism of these rocks, as it has of all the others adjacent to it. The nature and manner of intrusion of such enormous masses of granite are as yet imperfectly understood, but the present district offers exceedingly favorable conditions for a study of such phenomena. As, however, the problem is a large one and must be studied in its entirety, it is not within the province of this report to deal with it, except in such features as may come within the Elkhorn district.

Within the region herein described the granitic rocks are clearly of later origin than any other rocks. They are intrusive in the other igneous rocks and carry fragments of the latter. They abut against the truncated ends of the sedimentaries, and have undoubtedly displaced large amounts of both sedimentary and igneous rocks lying to the west of the present limits of those formations.

The granitic rocks of the batholith are extensively fissured. These fissures are grouped, and are much more prominent in some areas than in others, closely sheeted rocks occurring near areas showing no sheeting. The very striking bowlders and groups of monoliths that distinguish the granite area are due to the presence of these fissures. The fissures belong to two well-marked systems: (1) A system of vertical joints is most common, and produces a true sheet of the rock; the planes are vertical or approximately vertical, and are observable everywhere throughout the batholith, though the closeness of the sheeting planes varies greatly from place to place. Close spacing occurs in local areas, and may result in a platy structure of the granite; more commonly the fissures are farther apart and do not show except on weathered surfaces. The direction of the vertical fissures varies greatly in different parts of the batholith. In the Elkhorn area their strike varies widely, as is shown by the strike and dip marks on the geological map, Pl. XLV. In general, however, there is a tendency for the sheet to approximate parallelism with the contact line between the granite and the other rocks. (2) Diagonal fissures are always present, though often obscured by the more prominent vertical system. Their recognition is dependent upon their development by weathering. These diagonal fissures dip in opposite directions, the angle between them being 90°, though their strike is the same. The result is the intersection of the granite into rudely rhombic forms. Becker[1] has shown that such fissures are fault planes; that they never gape, but are mere cracks; that they are not partings or true joints; that they show movement by occasional slickenside faces and by measurable displacements usually of less than an inch for each fissure. The aggregate of such minute displacements he has estimated to be several thousand feet for the Sierras.

The batholith rock is remarkably free from inclusions of other rocks, even where it has broken irregularly through them. Only two small limestone inclusions have been seen in the granite at Elkhorn, and these are shown on the geological map. The first is a block of marble about 65 feet wide and 100 feet long; the second a mass of garnetiferous lime-silicate rock some 200 feet across.

The peculiarities of rock metamorphism observed on Crow Ridge give ground for the belief that the granite batholith extends under the sedimentary area of the district, the contact dipping to the east, but no direct evidence has been obtained to show that it does so here, as it does at other places about the borders of the batholith.

The andesites rest upon an eroded surface of sedimentary rocks as irregular as that seen in the district to-day, and it is therefore evident that the granite, where it is exposed near such contacts, was not covered by sedimentary rocks, but must have come against andesites. Moreover, in the central parts of the batholith remnants of an andesitic cover still exist, and the granite must have either penetrated between the andesites and the base upon which they rested or removed the basal rocks, whatever they were. A consideration of these relations and of the profiles shown in the cross sections shows that the batholith cover was never very great and probably consisted of 1,000 feet or less of andesitic rocks.

The formation of the granite batholith obliterated all evidences of the former character of the western part of the Elkhorn district. Since the batholith was formed there has been no further igneous activity within the borders of the Elkhorn district. To the west sporadic outbursts of rhyolitic magmas occurred at a somewhat later period, but as they often rest directly upon the granite they show that a long period of erosion intervened after the formation of the batholith, a period sufficient to permit the carrying away of the andesitic cover over a part, at least, of the area. In the Elkhorn district the work of erosive agencies has materially modified the surfaces, but the relative elevation of the peaks is probably the result of faulting in which north-south faults depressed the Elkhorn and Crow Peak area relatively to the Boulder Valley. Within the immediate district itself there is, however, little evidence of faulting. The sheeting or distorting of the granite has already been mentioned, but inasmuch as deformation by shear would scarcely show in the altered rocks if it were distributed over a considerable area, any slips or faults which might be individually insignificant would be rather large in the aggregate. Two cases of faulting were observed in the surface rocks. The first is a fault plane dipping east at an angle of 40° and cutting two small diorite dikes which permit a measurement of the displacement, which proves to be but 3 feet in the southern part. This is seen in the railroad cut 1,800 feet south of the station. A second instance is seen in the southern part of the district, where three faults, whose dip is N. 10° E. and whose angle of dip is 50°, traverse a block of Starmount hornfels and produce an aggregate throw of about 6 feet. These faults, like those seen in the underground workings, are small and seem referable to the granite intrusion.

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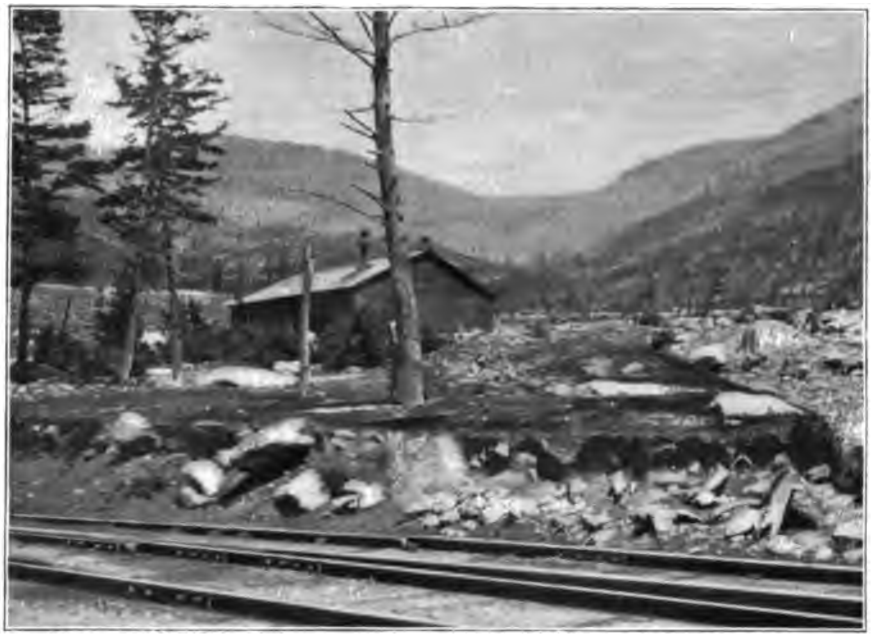
[1] Structure of a portion of the Sierra Nevada of California: Bull. Geol. Soc. Am., Vol. II, p. 50.

Concerning the later history of the region, it can only be said that it has suffered continued and prolonged degradation from ordinary atmospheric agencies since Miocene times, the only marked episode in its long period of erosion being that of local glaciation. The tilting which ponded the rivers of the State and filled the larger valleys with lacustrine débris has left no record of its action within this area, and, indeed, does not appear to have affected the general relations of the rocks. The amount of erosion that has taken place can not be reliably estimated. It is, however, evident that several thousand feet have been removed since the batholith was intruded, for the andesites of Elkhorn Peak were at least 1,000 feet thick on the western flank of the mountain, and over this area these rocks have been removed and the granite itself has been trenched to a depth of 3,000 feet or more.

GLACIATION.

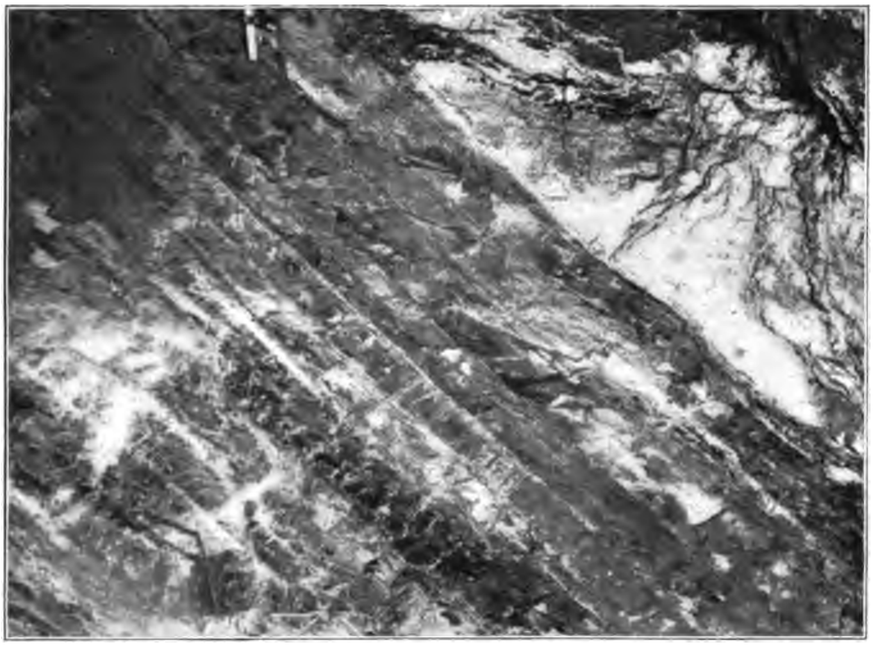
In the Elkhorn district the effects of glacial action are seen at several places in conspicuous morainal heapings and accumulations of bowlders. The most prominent moraine extends entirely across the valley of Elkhorn Creek above the town. This is well shown in Pl. L, *A*. There is a widespread distribution of bowlders in the mountain gorges that indent the side of Elkhorn Peak, but the district was never covered by a general ice sheet, the glaciation being purely local and of the alpine type. The snows of each winter accumulate to considerable depths in the amphitheater of Elkhorn Peak and exist as snow banks late into the summer, and through the Glacial epoch these amphitheaters were undoubtedly filled to a depth of 1,000 feet or more. This snow must have formed small glaciers during the early Pleistocene period, which pushed down the principal gulches, the largest glacier coming down Elkhorn Creek a couple of miles and depositing the bowlder material on which the town is built. Pre-Glacial erosion undoubtedly furnished an abundance of loose material, which, together with the blocks loosened by frost from the amphitheater cliffs, were borne on the surface of the ice or carried in its grasp to form the well-marked moraines now seen. The amphitheater walls show no evidence of ice erosion other than the removal of the débris and the general clearing out of the amphitheater. Rounded and ice-worn ledges of andesite are seen near the divide east of Elkhorn Peak. The amphitheater floors, however, show no rounded bosses, but are littered by bowlders which conceal the underlying rock. The water-filled glacial hollow, seen in XLVII *B*, and two similar depressions lying a half mile to the northeast are possibly rock basins, though the accumulation of débris prevents positive proof.

The glacier which flowed down Elkhorn Peak was formed by the confluence of two sheets, one coming from the marble cliff amphitheater south of Elkhorn Peak, the other from the amphitheater between Elkhorn and Crow peaks. The two glaciers united below Icy Lakelet, the pool shown on the map and in Pl. XLVII, *B*. The western glacier was the larger and crowded the lesser one toward the east, and in its retreat left great bowlders of granite scattered over the andesite slopes and upon the metamorphosed Mesozoic shales. The confluent ice sheet flowed down the valley to a point opposite the mouth of Alpreston Gulch, reaching an elevation of 6,300 feet. At a later period its front was about one-half mile above the town of Elkhorn, at which point the ice must have maintained a nearly constant position for a considerable length of time, as the terminal moraine at this point is unusually large for so small a glacier, being several hundred feet high and extending clear across the valley. As seen from the town, it completely dams this valley, as is well shown in the photograph taken from near the railroad station, Pl. L, *A*. This moraine shows a step-like profile, and consists of granite bowlders up to 10 feet in diameter, with smaller masses of andesite and hornstone, the whole forming mammillary hummocks with intervening kettle holes. This terminal moraine passes northward into a well-defined lateral moraine lying high up on the slopes west of the valley, while a much smaller lateral moraine is seen low down on the opposite eastern slopes. In the



A. BOWLDER MORAINE AT ELKHORN.

In the middle distance is seen a well-marked terminal moraine, extending across and completely damming the valley. Saddle between Elkhorn Peak (on left) and Crow Peak (on right) seen in background.



B BEDDING PLANE BETWEEN SLATE AND DOLOMITE, 2,200-FOOT LEVEL, ELKHORN MINE.

The illustration shows difference in fracture and well-marked bedding of the slate.

granite area at the head of Turnley Creek the moraine is less conspicuous, as the glacial bowlders are all of granite and aplite, and rest upon a granite surface, where they closely resemble the ordinary bowlders of disintegration common to the granite area. There is a strong contrast in the character of the glaciated and unglaciated areas. The valleys which have not been glaciated show steep sides and rounded bottoms, with firm soil and no swamps, while the glaciated parts of the same valley are paved with huge bowlders and show a scanty dark soil covered with rank vegetation and occasional swampy areas. The geological map, Pl. XLV, shows the extent of the ice-covered areas, the well-marked moraines being indicated by a darker tint than that marking the general extent of the bowlder heapings. It is evident that glaciation did not materially affect the topography of the region, though many of the picturesque aspects of the present scenery are due to its erosive action.

CHAPTER VI.

GENERAL EFFECTS OF THERMAL METAMORPHISM OF THE ROCKS OF THE DISTRICT.

The following account of the more prominent features of the thermal or contact metamorphism of the sedimentary rocks by the igneous intrusives presents only the more salient results of this action.

Both the sedimentary rocks and the later igneous rocks have been metamorphosed by the great bodies of molten magma intruded in them. This change, often called local or contact metamorphism, is herein designated hydrothermal metamorphism, because it is due to the heat and vapors of molten intrusion. Since it is caused by the igneous masses, the alteration is naturally greatest near them, and is less and less away from their borders. The changes due to thermal metamorphism differ very markedly from the results of ordinary rock disintegration, or rock alteration, and are also different from those changes which are due to metasomatosis. Thermal metamorphism embraces those changes produced in a rock mass by the influence of high temperature due to the intrusion of an igneous magma. These changes are of two kinds; first, physical; second, mineralogical. The physical changes are very marked. In limestones the alteration consists of a bleaching or whitening of the rock and its conversion into coarsely crystalline marble. In impure limestones the alteration results in marked mineralogical changes which give the rock an entirely different color, character, and appearance and make it usually coarser grained and harder than the original rock. The sandstones are altered to compact, almost flinty quartzites. The clay shales and the associated rocks, which consist largely of clay, together with calcareous or siliceous matter, are intensely altered and most commonly are found to form very dense, hard rocks of extremely compact texture which break with a conchoidal fracture and which, because of this compactness and smooth fracture, are often called hornstones. These hornstones have lost almost all trace of the original plane of bedding. They break in either dicy or rhomboidal bits, and the original stratification can be determined only by faint color bands. Very often, however, even this criterion is difficult to distinguish unless weathering develops a surface on which the original bedding plane is indicated by slight ridging. In none of the altered rocks at Elkhorn is a true slaty cleavage developed, either by thermal metamorphism or by other changes. In the less altered rocks a lamination which approaches a slaty structure in general appearance may still be observed, but in this case, as, for instance, that of the hanging-wall rock of the Elkhorn lode, the apparent slaty cleavage coincides with the original bedding of the rock or is due to slipping along bedding planes.

The mineralogical changes are those due to a rearrangement of the material composing the rock, a change in which new chemical combinations are effected and new minerals formed. In pure calcareous rocks the limestone is simply recrystallized and forms a marble whose coarseness of crystallization is in a way a measure of the intensity and duration of the heating of the rock.

The argillaceous rocks commonly contain silica, and recrystallize as aluminum silicates. The pure siliceous rocks recrystallize as quartzites. It is apparent that without the addition of material from outside, as, for example, by pneumatolytic action, the pure silica and pure lime rocks do not change in mineralogic composition. Where, however, the rocks are mixtures, as is so commonly the case in sedimentary strata, they are strikingly altered. The siliceous calcareous shales form coarse and patchy aggregates of lime and magnesian silicates. Diopside and garnet (the lime-aluminum garnet, grossularite) are very common, and, if iron is present, epidote occurs in abundance.

Arenaceous rocks.—Sandstones are but little affected by thermal metamorphism unless they contain impurities. A pure quartz sandstone will recrystallize as a quartzite if the temperature be sufficiently high, and this has happened at many places in the district. As a rule, however, the alteration consists in a hardening of the sandstone and not an entire recrystallization. If the original rock was impure—and impure sandstones are especially common in the Mesozoic strata composing the long spur of Crow Peak lying to the northeast of Elkhorn—the resulting product may not have any resemblance to the quartzite, but may consist of garnet, mica, etc.

Argillaceous rocks.—The shales are commonly baked or altered to a dense, flinty product known as hornstone, which breaks in angular chippy fragments and commonly has a well-developed cubical fracture, often breaking into cubes. It is usually dark colored, has a very homogeneous and very finely granular texture, which is sometimes sugary. These pass into those forms in which the metamorphism has been greater and the rocks are light colored, white, pale green, lavender, or pink, and have the texture and appearance of a fracture surface of porcelain. A perfectly pure argillaceous rock would form micaceous schists, but most of the shales contain impurities which determine their alteration to compact, fine-textured rocks consisting of various alteration minerals. In this district the spotty slates and flecked rocks seen in similarly metamorphosed areas elsewhere were not observed. Such spots are due sometimes to carbonaceous matter where the rocks are slightly metamorphosed, or in more altered forms to areas free from mica. At Elkhorn extreme metamorphism has resulted in the formation of extensive masses of compact-textured rock which are best grouped as hornstone.

Calcareous rocks.—The most striking effects of hydrothermal metamorphism are produced in the impure argillaceous limestones or calcareous shales. In these rocks the carbonic acid is completely eliminated and the whole is converted into a lime-silicate rock. As the alternating strata frequently consist of very different original material, the resulting rock varies greatly in appearance and may consist of aggregates, often coarse, but commonly fine grained to compact, of lime-rich silicates, with quartz, biotite, etc.

Fumarolic alteration.—The presence of tourmaline and axinite shows that there has been fumarolic action as a result of the vapors of the cooling igneous rocks. That such vapors are developed in large quantities by magmas is well known from observations on active volcanoes as well as abundant evidence about which there can be no doubt. Such vapors would naturally penetrate along fissures or porous strata and produce marked alteration.

The impregnated bed of garnetiferous hornstone which constitutes the ore body of the Dolcoath mine may have originated, as suggested by Dr. Barrell, from the shrinkage induced in a stratum of impure limestone contained between beds of pure limestones which have suffered little change in mass or volume. In the metamorphism of the impure stratum the carbonic acid is driven off and the rock loses upward of 30 per cent of its weight and 50 per cent of its volume, and, being steeply tilted before metamorphism, the result would be a porous layer whose formation may be likened to that of terra cotta or brick from clay. Such a porous layer would afford ready passage for fumarolic vapors or mineralizing gases. The ore stratum is evidently an altered limestone bed. It is 15 to 18 inches thick and dips E. at 55°. The ore occurs as silvery spots from 1 to 25 mm. across, and is often associated with calcite scattered through the rock. It consists of telluride and sulphide of bismuth carrying gold. The ore is apparently confined to this narrow stratum because its porosity is greater than that of the adjacent and confining limestone beds. The rock holding the ore consists of nearly equal parts of diopside and grossularite with calcite, as noted in the appendix. The ore occurs with diopside as well as with calcite. The latter is evidently a product of later infiltrating solutions, as it forms veinlets and fills the cavities lined with crystals of garnet, diopside, etc., with poikilitic calcite crystals.

CHAPTER VII.

MINERALS OF THE ORE DEPOSITS OF THE DISTRICT.

The ore bodies of the Elkhorn district contain but few mineral species, and most of them are of common occurrence in ore deposits elsewhere. The oxidized portions of the Elkhorn lode have, however, yielded native silver in crystalline aggregates of extreme beauty, the specimens being equaled in America only by those of the Batopilas mine in Mexico, while the calamine, found abundantly in the upper levels of the Elkhorn mine, is perhaps the finest crystalline material yet found in this country.

The minerals composing the contact-metamorphic rocks, which constitute the gangue of some of the ores in the lesser deposits of the district, are sometimes finely crystallized. This is particularly true of axinite, but garnet, epidote, and other minerals also occur in crystalline masses.

ORE MINERALS.

The ore minerals proper include the metallic sulphides, galena, bournonite, tetrahedrite, pyrite, and blende, with indeterminable rich silver sulphides. The decomposition or oxidized products of these sulphides, found in the upper parts of the deposits, include native silver, cerussite, calamine, a little minium, malachite, horn silver, linarite, aurichalcite, and descloizite. Accompanying these the gangue minerals quartz, dolomite, and calcite occur, together with fragments of country rock, garnet, and pyroxene.

Galena (*sulphide of lead*).—Argentiferous galena forms ore bodies in the Elkhorn, Queen, and C. and D. mines, as well as in a number of prospects. It occurs massive, is usually coarsely crystalline, and is commonly associated with blende, and sometimes with pyrite. It is frequently somewhat shattered, and crumbles readily on being struck with a hammer. No well-formed crystals were seen, nor any material of undoubted secondary origin. It occurs in bunches or pockets with the pyritic ores in the C. and D. mine, and forms great masses in the foot-wall limestone of the Elkhorn mine, which, upon extraction, left large caverns.

Bournonite.—This antimonial sulphide of copper and lead occurs sparingly in the quartzose ores of the Elkhorn mine. No well-crystallized specimens were seen, the mineral occurring as grains scattered through the quartz and somewhat resembling the more common tetrahedrite.

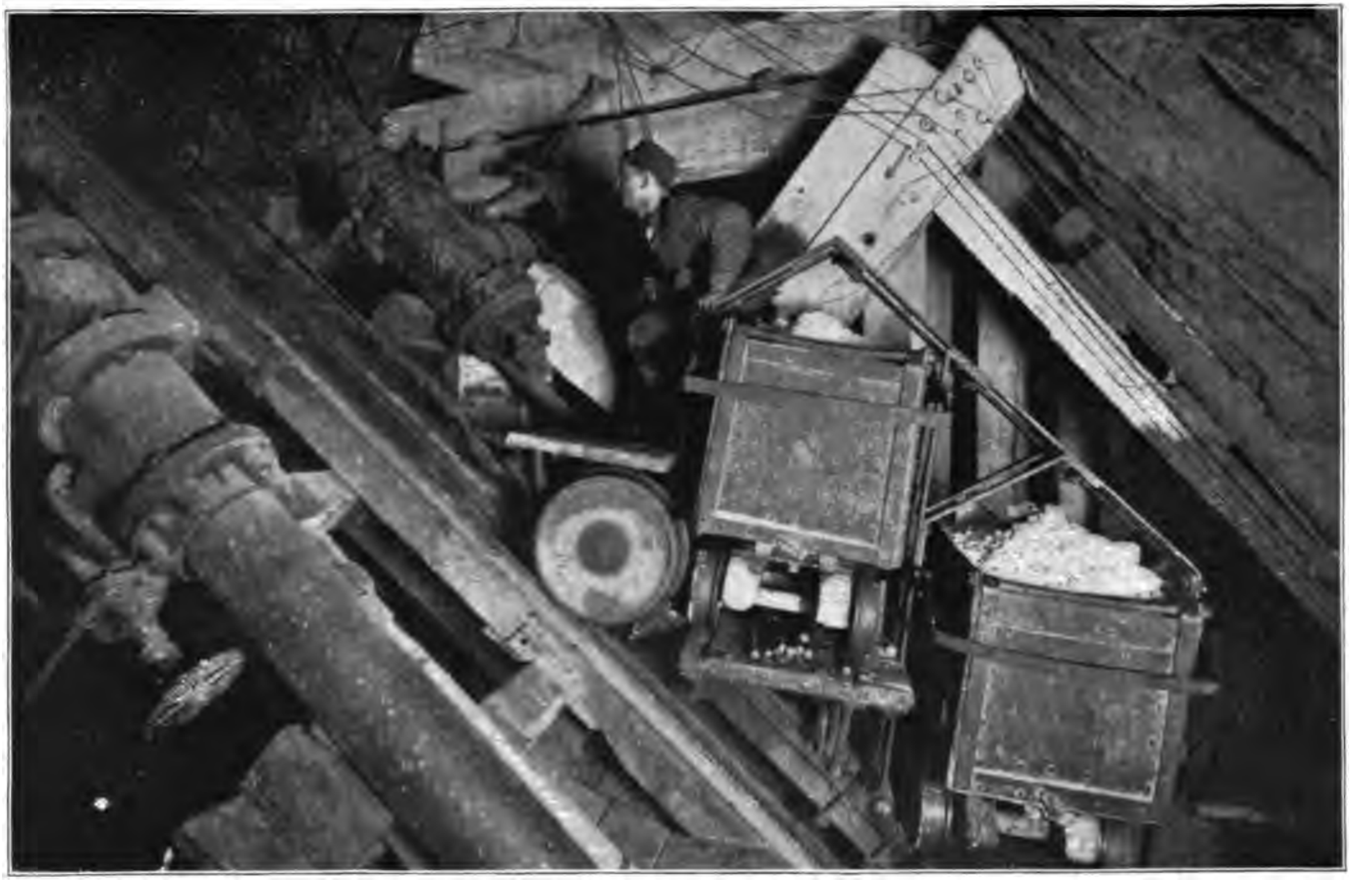
Tetrahedrite (*gray copper ore*, *antimonial sulphide of copper*).—This mineral occurs abundantly in the Elkhorn mine, where it is highly argentiferous, and probably also contains lead. It is always coarsely crystalline and massive, and occurs in grains and masses in the quartzose ore, where it is associated with pale-brown blende. It is rarely found in the foot-wall bodies, and is then also associated with quartz. It is probably the parent mineral of the native silver and silver-rich oxidized quartzose ores of the mine.

Pyrite (*iron sulphide*).—This is of common occurrence, not only in the Elkhorn mine, but in all the prospects of the district, and is also found in grains scattered through the igneous rocks, particularly the gabbro and the diorite-porphyry. In these rocks it is in part of primary origin, but mainly secondary formation, and was undoubtedly derived from the augite and other ferromagnesian minerals by the action of mineralizing solutions or vapors in the ore bodies. It is usually massive, very light colored, and forms the bulk of the ore in several mines. In the Elkhorn mine, though abundant, it does not form a large part of the ore, and is usually massive. In the drusy cavities in the massive pyritic ore well-crystallized specimens have been found which show the usual well-formed pentagonal dodecahedron; more rarely it occurs in cubical form. Assays made of the pyritous ore show it to contain silver, but as the massive material usually contains admixed particles of galena it is probable that the silver comes from them.

Tetradymite (*sulphide and telluride of bismuth*).—This mineral occurs in grains up to one-eighth of an inch across in the garnetiferous rock of the Dolcoath mine. It is somewhat altered in the oxidized material for a few feet below the surface, and then shows masses of free gold having the usual rusty or bronzy tint of gold derived from a telluride. The fresh mineral is brightly metallic, with the usual silvery luster, and shows a distinct foliation. Tests made in the chemical laboratory show it to be a mixture of bismuth telluride and bismuth sulphide. In altering, the mineral loses its laminated character and the folia become fibrous. It occurs in minute grains disseminated through the garnet, and in larger grains associated with calcite in the massive garnet of this mine. The origin of the ore deposit and the genesis of the mineral is discussed in an account of the Dolcoath mine.

Bismuthite (*sulphide of bismuth*).—This mineral occurs intimately associated with, and in the specimen is indistinguishable from, tetradymite. It is found only in the Dolcoath mine, and its presence was determined by chemical analysis by Dr. H. N. Stokes in the Survey laboratory.

Blende (*sphalerite*, *zinc sulphide*).—This mineral occurs associated



INCLINE SHAFT OF THE ELKHORN MINE.

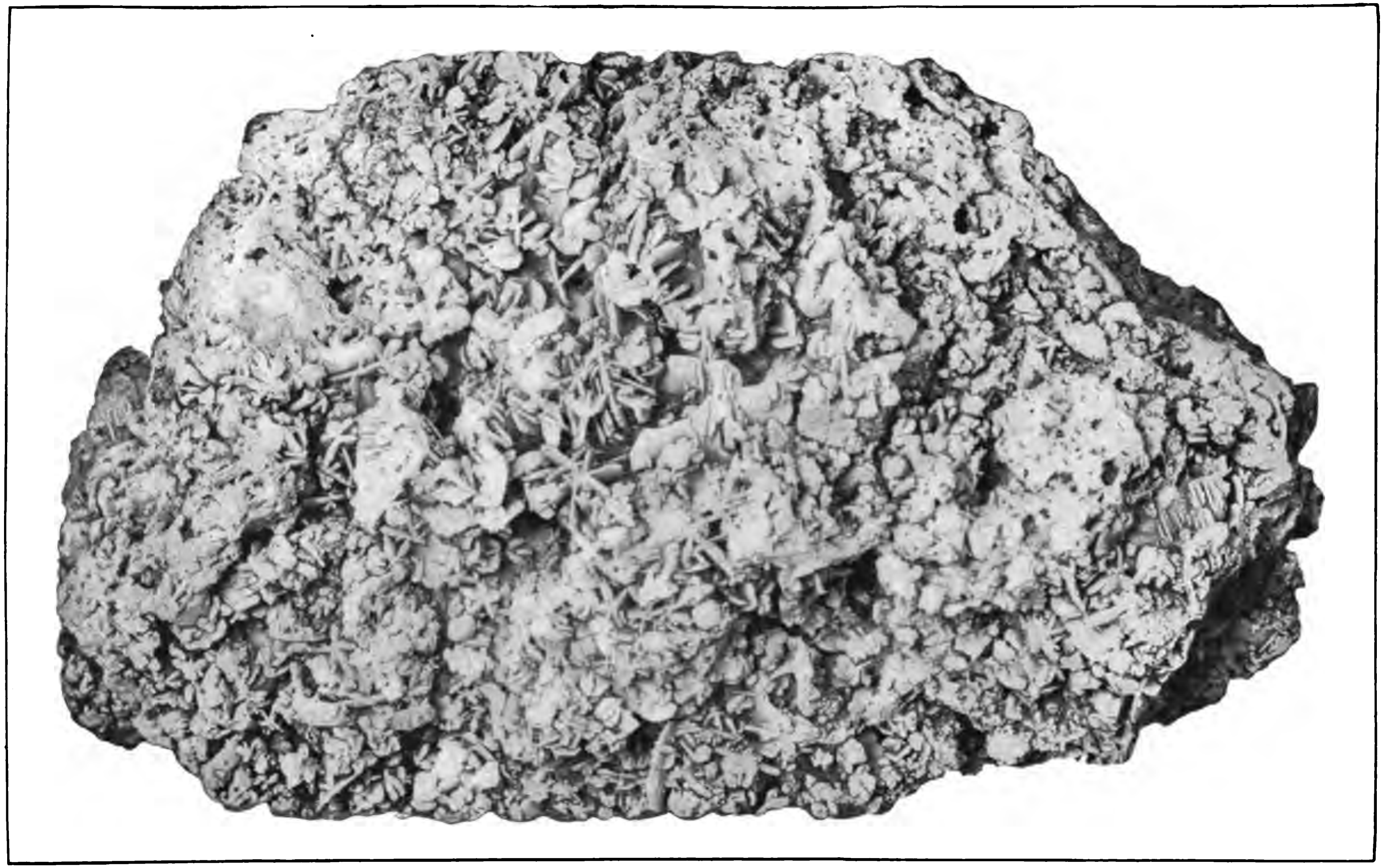
Shows method of timbering station, arrangement of pump pipes, and method of hoisting ore on two platform skips; slate "hanging wall" is seen above the skip.

PLATE LII.

PLATE LII.

CERUSSITE.

This plate shows a photograph of a specimen of cerussite in which the rosettes consist of plates that are relatively small and are coated by a film of quartz, so that this specimen is not so fragile as those commonly seen. The cerussite is in part, at least, formed upon nucleal fragments of oxidized quartz ore, but cerussite makes up the greater portion of the specimen. The reversed side shows a coating of minute calamine needles upon the quartz that encrusts the cerussite. The crystals are about one-fifth the size of some that were seen. Illustration is one-half natural size.



CERUSSITE CLUSTER FROM ELKHORN MINE.

with galena and pyrite, and in lesser amounts with tetrahedrite, in the ores of the Elkhorn mine and in all the galena ores of the district. It has commonly a dark-brown, resinous luster, is massive, and shows a coarsely crystalline texture. In the Elkhorn ores it varies from a very pale creamy brown, usually showing flakes of red in the quartzose ores, to a deep brown when associated with galena and a blue black when associated with pyrite. It is very rarely seen as a secondary mineral associated with pyrite and calcite in cavities in the original ore. In this case it forms well-shaped crystals one-eighth to one-fourth of an inch across, and is of undoubted secondary origin. The massive material of the ore body shows shattering, with cementation of the fragments by silica. Blende from the Elkhorn mine is commonly supposed to carry silver, and the red blende, especially, to carry high values in silver. This, however, has not been borne out by the assays made for the writer; in fact, owing to the common admixture of galena particles, it is impossible to obtain absolutely pure material for assay, and therefore there is some doubt in the case of this mineral, as well as in that of the pyrite, whether the silver contents are not derived from the galena.

Calamine (*hydrated silicate of zinc*).—This mineral occurs in drusy coatings lining cavities in the oxidized portions of the ore bodies of the Elkhorn mine. It forms radiated groups of spatulate crystals, usually somewhat stout and of the common form, in which the brachypinacoid forms the broad face and the prism is relatively small. The Elkhorn material is of two kinds. The first occurs associated with the limestone, in which case the calamine rests on a crust of pale yellowish-green, botryoidal material one-eighth to one-sixteenth of an inch thick. Above this there is often a film or thin crust of bright-green carbonate of copper, upon which the calamine rests in a mass from one-half of an inch to an inch thick, composed of bunches of radiating crystals. This material has a very delicate-green tint, although it is commonly transparent. The crystals show their form very distinctly, but are twinned and occur in groups, so that crystals for measurement are not obtainable. In the entirely oxidized parts of the ore body, where the limestone has been dissolved away and only the cellular films of silica are left, calamine occurs lining the cavities with thinner and more fragile crystals than those just noted. These crystals also are perfectly clear and colorless and rest on a film of silica. The derivation of the calamine is undoubtedly from the oxidation of the blende, and its occurrence in the mine is such as to leave no doubt on this subject. Small druses were broken open in which the cavities were filled with water and in which the calamine crystals were apparently still forming.

Cerussite (*lead carbonate*).—Very beautiful masses of crystalline cerussite were obtained from the upper workings of the Elkhorn mine. It occurs in six or eight stellate groups, the rays being formed by plates scarcely thicker than a sheet of paper, and sometimes reaching dimensions several inches across. Pl. LII is from a photograph of a specimen showing relatively small crystals. The more common occurrence is as a massive material coating galena, from which it is quite evidently formed. This material is usually clear and glassy, with a leady luster, and can be traced into the parent mineral. The galena alters along cleavage cracks, and every gradation may be observed between the fresh and unaltered material and the cerussite. Ashy-gray, loose-textured masses also occur, but are less abundant. In the upper workings of the Elkhorn mine large quantities of carbonate ore were extracted, the cerussite occurring in massive form and associated with various impurities.

Linarite (*hydrated sulphate of lead and copper*).—This mineral is rare, but good specimens with the usual azure-blue color, from the Elkhorn mine, were seen in the collection of Mr. Walter S. Kelley.

Chalcopyrite.—This occurs in the Dolcoath ores and rarely in the Elkhorn mine. It is massive and occurs associated with pyrite.

Gold.—Native gold was seen in the ores of the Dolcoath mine, particularly those in which the tetradymite has been partially or wholly altered. The color is deep bronze yellow.

Silver.—Native silver was abundant in the thoroughly oxidized portions of the Elkhorn mine. Its most interesting occurrence is in branching clusters of crystals, a few of which are shown on Pl. LIII. No large crystals were obtainable at the time of visit. These clusters occur attached, often only by the base or stem of the fern-like cluster, to the iron-stained siliceous decomposition product which forms the gangue of the upper part of the lode. Silver also occurs as sheets or scales in cracks and coating surfaces of less altered material. In the clusters the crystalline form is very clearly recognizable, though the material is not especially adapted for crystallographic study.

Pyrolusite (*black oxide of manganese*).—This occurs in little spots coating calamine, and as dendritic markings on the yellow, partially altered dolomite of the Elkhorn mine.

Azurite (*blue carbonate of copper*).—This is found in the Elkhorn mine in minute clusters or as a blue stain; also in numerous prospects, particularly the ores of the Copper King.

Malachite (*green carbonate of copper*).—This occurs as a green stain and in earthy masses in the oxidized ores and as green crusts in botryoidal forms associated with calamine in the Elkhorn mine. It is found only in small amounts. It also occurs in many prospects of the district.

Hematite and magnetite.—These occur, intimately associated, in the iron ores from the mines on the north side of Elkhorn Peak, near the summit. No specular or crystallized material was seen.

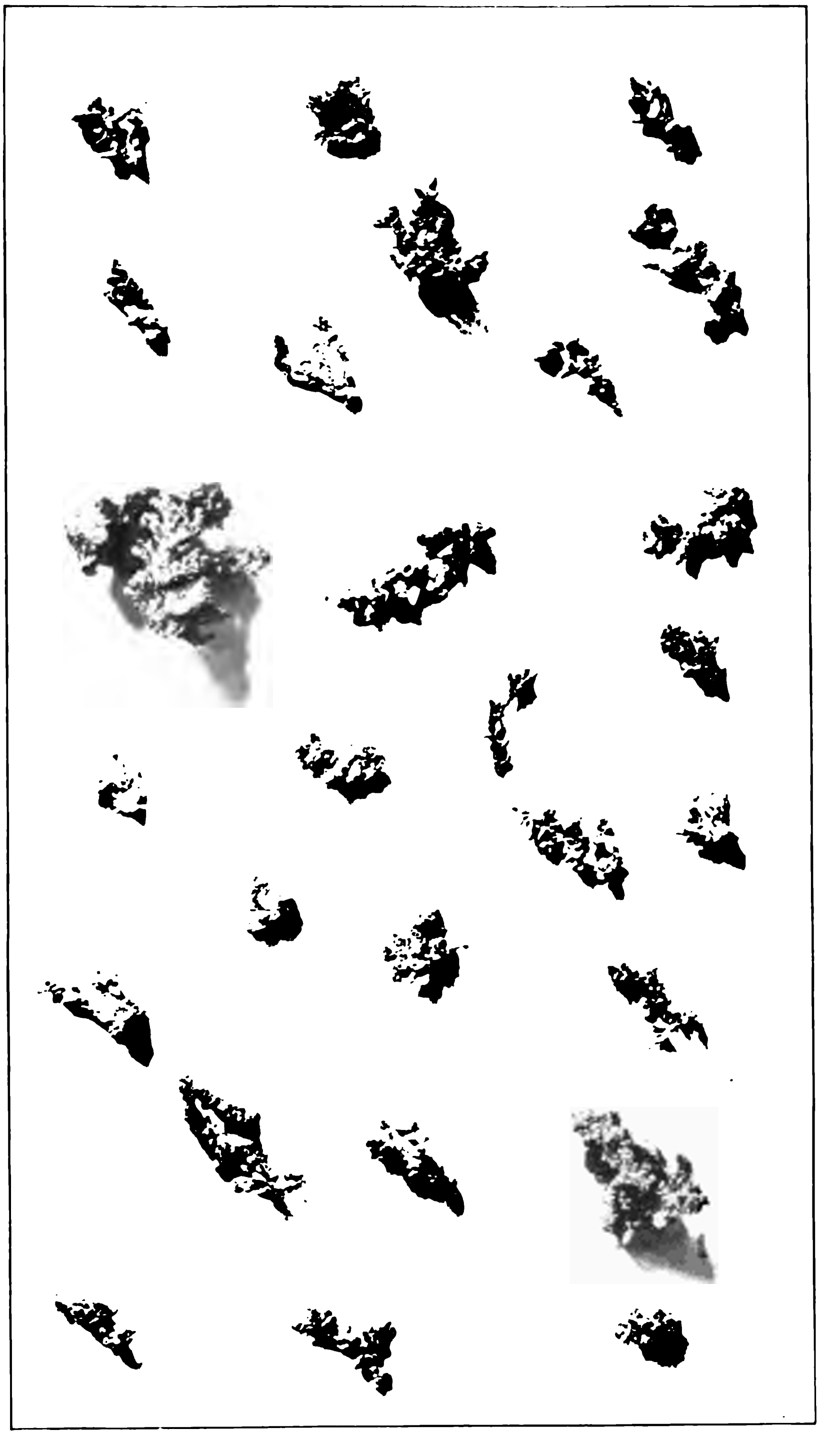
Limonite (*brown hematite*).—This mineral occurs as earthy masses

PLATE LIII.

PLATE LIII.

NATIVE SILVER FROM ELKHORN MINE.

This plate shows a number of pieces of arborescent and dendritic native silver from the ores occurring in the upper part of the Elkhorn mine. The specimens are very much smaller than many of those which were found in the development of the property. The silver occurs loosely attached to an oxidized siliceous gangue. The crystals are often flattened and elongated and form complex groups or aborescent forms, usually attached to the base of the fern-like mass, although the specimens show definite crystal forms. The edges are often rounded and the faces dull, so that the material is not fitted for crystal measurement. The forms, however, are undoubtedly those common to native silver and present no novelty in this respect. Although native silver was of common occurrence in the uppermost parts of the oxidized ore bodies at the mine, none of the common wire silver, seen as an alteration product of the rich silver sulphides at so many mines in the State, has been found at Elkhorn. Scales and plates of native silver also occur in cracks in masses of amorphous white and red silica.



NATIVE SILVER FROM ELKHORN MINE.

at many places in the district. It is common in the rusty outcrops of mineral veins.

Descloizite (*vanadinite of lead and zinc*).—This occurs in thin, mossy, dull yellow-green crusts of minutely crystalline surface, coating cavities in a deposit of greenish and red-colored amorphous silica from the hanging-wall ore body of the 1,300-foot level of the Elkhorn mine.

Aurichalcite (*basic carbonate of zinc and copper*).—This occurs in bunches of pale-green, silky needles, filling cavities one-half to three-fourths inch across in oxidized siliceous ore of the Elkhorn mine.

Smithsonite (*zinc carbonate*).—This is found associated with calamine on dolomite fragments of oxidized parts of ore bodies. It forms gray crusts 1 mm. thick, with drusy surface, covered by a second crust of pale apple-green botryoidal material showing both radial and concentric structure. This latter crust varies from 1 to 5 mm. in thickness, and the green tint is due to a small amount of copper. Malachite crusts often rest upon the smithsonite and are in turn coated by green calamine.

Pyrrhotite (*magnetic pyrite, iron sulphide*).—This mineral occurs in small amounts at several of the ore bodies of the district. In the Elkhorn mine it is found associated with pyrite, as a massive coating around cubes of pyrite in the white dolomitic marble of the bottom levels of the mine.

GANGUE MINERALS.

The minerals just enumerated occur associated with the valueless gangue minerals. These are few in number, embracing quartz, calcite, dolomite, garnet, and diopside.

Quartz (*crystalline silica*).—Quartz is almost universally present in the ore bodies of the district. It forms the hanging wall of the Elkhorn mine, and is abundant also in the foot-wall bodies. It occurs in every form from coarsely crystalline to extremely fine crystalline textures, and is clearly a replacement quartz in many cases, while in others it has the coarse comb structure characteristic of the filling of open spaces. Groups of large crystals are rarely found, and the mineral has no especially interesting feature aside from its genetic relations.

Calcite (*lime carbonate*).—This occurs abundantly throughout the Elkhorn mine, where it forms crystalline coatings of well-shaped rhombohedra in drusy cavities in the lead ores associated with zinc, and also occasionally in stalactitic forms in small cavities and water courses.

Dolomite (*carbonate of lime and magnesia*).—This forms the white marble foot-wall country rock of the Elkhorn lode. It is very uniform in texture and in composition. No well-shaped crystals have been seen.

Garnet (*variety grossularite*).—This lime-alumina garnet is common in the metamorphic rocks of the district. It occurs as a gangue mineral in the Dolcoath mine, where it is massive and is mixed with diopside in the stratum containing the ore. It is the product of the alteration by contact metamorphism of an impure limestone. The color is usually a cinnamon brown, and the mineral alters to a greenish chlorite. Crystals are seen penetrating the calcite in this ore. It occurs mixed with magnetite in the ore from the iron mines on the summit of Elkhorn Peak, where it is glassy, and has a dull greenish-yellow color.

Diopside (*lime-magnesian pyroxene*).—This form of pyroxene is found abundantly as a contact mineral throughout the district, but its only occurrence as a gangue mineral is in the Dolcoath mine, where, as just noted, it is mixed with garnet. It has a pale yellowish-green color, and occurs only massive, no crystals being observed.

Serpentine (*hydrated silicate of magnesia*).—This mineral occurs as an alteration product of diorite in the Elkhorn mine, and also in the railroad cuts near that property. It occurs also as an alteration product of garnet (?) in shells surrounding fragments of limestone included in the andesites of Elkhorn Peak. It is not, strictly speaking, a gangue mineral.

Axinite (*boro-silicate of aluminum with varying amounts of iron and manganese*).—This mineral occurs both as a rock constituent in the sediments altered by contact metamorphism and as the filling of little veins in such rocks. It is found abundantly in coarse crystalline masses in such veinlets at the prospect tunnel driven in from the creek bed 1½ miles above Elkhorn. The specimens are of a dull-grayish plum color, in lamellar aggregates of crystals usually striated. It occurs associated with calcite.

Tourmaline (*basic or subsilicate of boron, alumina, potash, lime, magnesia*).—This mineral occurs sparingly in the contact-metamorphic rocks that inclose some of the smaller ore bodies disclosed by shallow prospect pits on the eastern side of Alpreston Gulch and vicinity. It also occurs as stout black crystals, often having a rusty coating, in the center of altered fragments of marmorized limestone included in the andesite.

Epidote (*orthosilicate of lime, alumina, and iron,* $H\,Ca\,(Al\,Fe)_3\,Si_3\,O_{13}$).—This occurs abundantly in the contact-metamorphic rocks formed from impure limestones. It is common near Black Butte, where it forms fascicles whose fibers are several inches long. This material is associated with calcite and axinite.

Wollastonite (*silicate of lime*).—This occurs as a constituent of the contact-metamorphic rocks, particularly the slightly impure marbles, in which ore bodies occur. It is seldom in masses recognizable to the naked eye.

Microcline.—This mineral occurs in white, coarsely massive form in the syenite dikes of Queen Gulch, but is not associated with the ore deposits. Various other minerals occurring as rock constituents are mentioned in the petrographic description of the igneous and the contact-metamorphic rocks.

PARAGENESIS.

A study of the ores from the Elkhorn mine shows that the primary sulphide minerals were deposited at the same time. There is, it is true, oftentimes a distinct coating of pyrite about isolated grains of galena, but in the massive ore the minerals interlock and show no evidence of difference in age. Moreover, there is no crustification in the primary ore; later fracturing has sometimes permitted infiltrating solutions to deposit secondary quartz which, though usually barren, does sometimes hold galena and tetrahedrite. The pyritic ore from the lower levels sometimes shows drusy cavities coated by distinct crusts. In this case the oldest crust resting against the primary sulphide ore is sometimes pyrite, and more often the following succession is seen:

A. Pale-yellow, opaque blende.
B. White calcite in well-shaped rhombohedra.
C. Pyrite in well-formed pentagonal dodecahedrons.
D. Clear and transparent resinous blende in distinct crystals.
E. White calcite in well-formed rhombohedra.
F. Quartz crystals in clusters.
G. Isolated pyrite crystals resting on the points of the quartz.

The entire succession is not always shown. It is evident that observations made upon these small druses can not be relied upon to furnish any conclusive evidence as to the manner of deposition or the chemical changes involved in the formation of the Elkhorn deposits.

As to the association of the minerals, it has been observed that where the ore contains tetrahedrite it commonly holds a light pale-brown zinc blende, and that pyrite is either absent or is present in insignificant amounts. Bournonite sometimes, though rarely, occurs with tetrahedrite, but is never found with blende. As a rule, both bournonite and tetrahedrite occur only in quartz and are not found as direct replacements of limestone, while the ores that contain the most blende are low in silver.

CHAPTER VIII.

THE ELKHORN MINE.

History of the property.—The ore deposit known as the "Elkhorn" mine was located as the Holter lode on January 2, 1875, and was worked nearly continuously from that time until November, 1899. The general history of the property has already been mentioned in giving that of the district. The New Elkhorn Mining Company stopped work in the mine in the autumn of 1899, and as the pumps were withdrawn, the surface machinery dismantled and sold, and the mine practically abandoned, it was generally understood that this great producer was worked out and the last chapter of its history completed. The entire property, including such surface improvements as were of value, was sold to two successful mining operators for $20,000 early in 1900, and it was generally supposed at that time that only the dump heaps would be worked. The new owners decided, however, to reopen the upper levels of the mine, and the property is now (May, 1901) being equipped with the necessary machinery for working, and promises to again become a producing property. The abandonment of the mine by the English corporation was primarily due to the exhaustion of the rich ore bodies, for although more or less ore remained, it was of too low grade to pay expenses, owing to the heavy expenditures necessary in pumping the mine, which were over $1,000 a week; this, and the small number of men scattered over so large a mine working the low-grade patches and remnants of ore bodies left in previous years, made the cost per ton excessive. Thus the actual cost of mining exceeded $15 per ton, including all expenses. Milling cost $9, owing to baseness of the ore, and for a long time the reduction works were run on a profit of only 50 cents per ton, thus necessitating very close working.

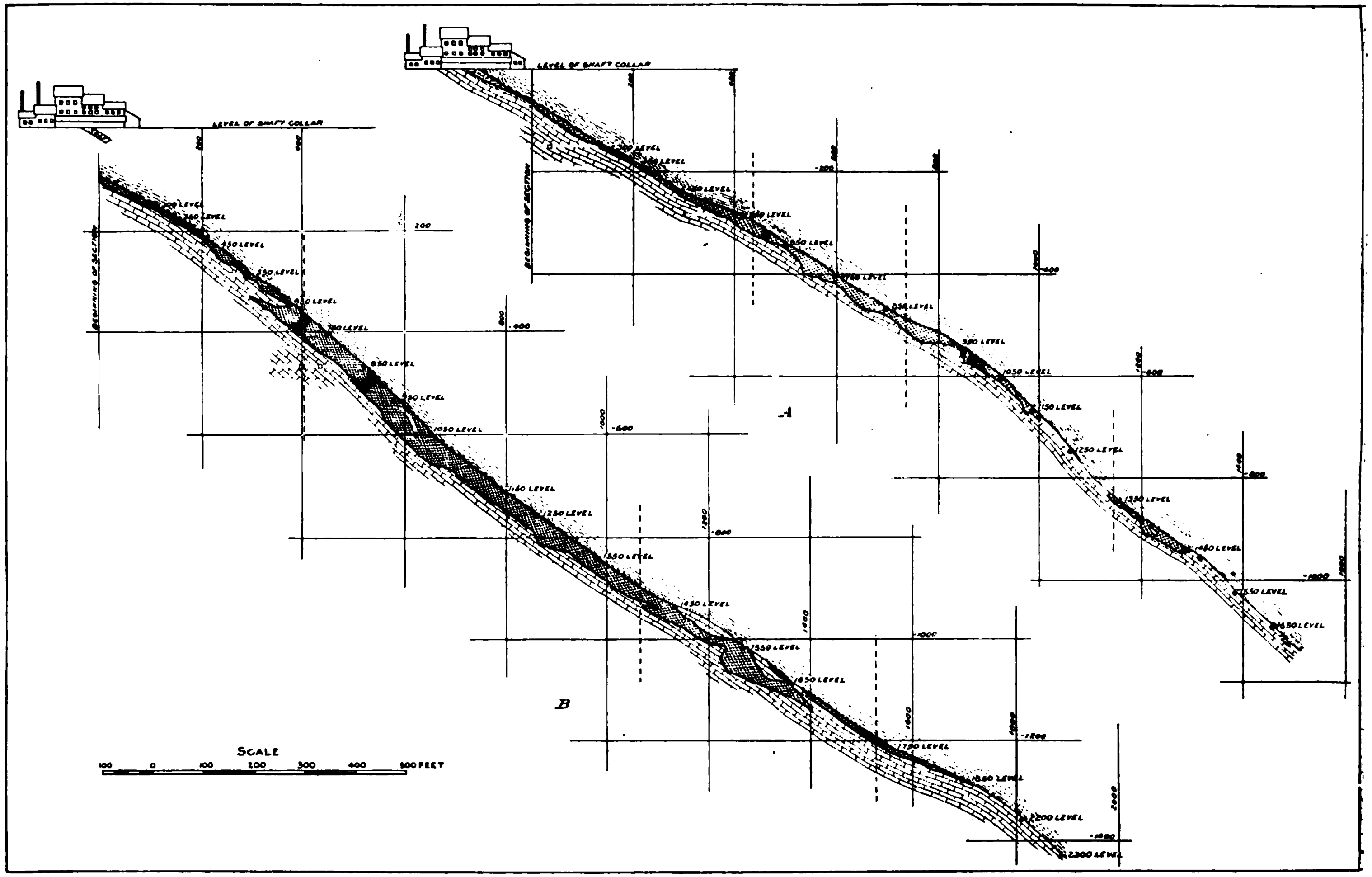
General features of the ore deposit.—The ore deposit does not constitute a true vein, though commonly spoken of as a vein or lode. The ore occurs in two principal shoots lying on the under side of folds—i. e., in the saddle of the folds—and conforming to the dip of the stratified beds in which they occur. These ore bodies are found along a bedding plane between indurated shale (hornstone) and dolomitic marble. This contact plane was followed in mining and has commonly been spoken of as the lode. Although there has been some slipping and movement along this plane, the contact is not mineralized, nor does it show any vein quartz or other lode material except in the steeply pitching arches underneath which the ore bodies occur. The ore deposits consist of more or less irregular bodies of rudely lenticular cross section lying against the hanging-wall hornstone, and as isolated masses forming so-called "chamber" deposits in the underlying dolomite. The hanging-wall bodies consist of quartz carrying ore minerals and are practically continuous from the top to the bottom of the mine. The lead chambers are isolated bodies connected by fissures or rusty stringers with quartz ore shoots, but of irregular shape and position, and often of large size. They are not cave deposits, and the term "chamber" applies only to the caverns left by the extraction of the ore, no original cavernous open spaces occurring. While there may be honest doubt concerning the formation of galena deposits in open caverns in limestone at many American localities, the facts to be described herein preclude any such theory of formation.

Topographic relations.—The ore deposits occur, as may be seen by reference to the map, Pl. XLV, in the relatively broad and open valley of Elkhorn Creek, where the more readily weathering limestones have been eroded into a basin whose bottom is now filled and leveled by morainal material. This position, as may be seen from the topograpic map, Pl. XLII, is a relatively low one and receives the drainage from a large area of impervious rocks forming the high peaks near by. It is, as it were, the apex of a funnel composed of the snowy amphitheater of Elkhorn and Crow peaks and their adjoining ridges. Though the creek bed is in morainal wash, so that the stream before diversion often carried flowing water past the mine, a large part of the precipitation and run-off of the northern part of the district finds its way into the altered limestones, in which it has formed subterranean waterways. It should, however, be remarked that no large caves have been found, and the smaller waterways noted in underground exploration are evidently later and not in any way connected with the ore bodies.

Geological relations.—The ore deposit occurs in a dolomitic limestone forming massive beds and overlain by altered shale. The strata dip steeply, the angle varying from 35° to 55°, this attitude being due to the uplift and folding of the entire Paleozoic and later rocks into a series of parallel mountain folds that extend eastward to the valley of the Missouri at Townsend. As shown in a previous chapter, all the sedimentary strata seen in this district form part of the eastern side of an arch, the spur formerly occupied by the west limb of this anticline being now occupied by the granite batholith. This structure, as understood from the surface relations near the Elkhorn mine, is shown in the cross section 2 of Pl. XLVIII. The half arch now forms a monoclinal fold composed of all the various beds seen in the Elkhorn district. The uniformity of the monocline is, however, disturbed by several minor corrugations which have been noted in the earlier chapters. The ore deposit occurs in two of these lesser flexures, which coalesce near the surface and form one relatively broad arch. These arches pitch steeply to the north. The gabbro-diorite intrusion, which has been described in a previous chapter, breaks through the limestones and shales, and has shattered them, sending out forks and tongues of diorite and allied rocks into these irregular breaks. Such intrusions are seen on the surface to the northwest and southeast of the mine, and are encountered in an exploratory drift under ground, and, though they have no direct connection with the ore bodies and do not make ore where they occur, it is believed that the main gabbro mass is the source from which the metallic contents of the deposits have been derived. These lesser diorite intrusions are seen in the mine in the long south extension of the 650-foot level.

Outcrop.—South of the mine buildings, shown in Pl. XLIII, the outcrop of the ore body is obscured by morainal débris and has not been found. It has not been recognized in the railroad cut opposite the town, and in fact at that point the diorite breaks across the contact plane along which the ore body occurs farther north. To the north of the mine the outcrop is seen in the railroad cut back of the boiler house, where the rocks have a strike of N. 50° W. and dip at 30° to 50° NE. Some 30 feet of the foot-wall sand rock or dolomite is exposed, with 150 or 200 feet of thin-bedded argillaceous shales lying upon it. The outcrop could not be traced on the surface beyond this point, but is said to have been opened by prospect pits at a number of points. Silicified limestones occur immediately south of the tailings dam on the south side of the mill. The rocks are part of the Keene limestone and show brecciation and replacement by siliceous waters. It is therefore evident that the mineralizing solutions were not confined to the immediate channels in which the ores of the Elkhorn mine were deposited, though, so far as known, the ore bodies formed near by are not workable.

Hanging-wall hornstone.—The ore bodies are sharply delimited by a hanging wall of argillaceous rock. This rock is dense and tough, and corresponds to what some geologists call hälleflinta, but which in this report has been called hornstone, following the nomenclature of Rosenbusch. The rock is well bedded, as shown in Pl. L, *B*, but does not possess either a shaly or a slaty cleavage, but breaks into splintery fragments along a system of fine jointing, thus forming cubical masses. The term argillite does not apply to it, as strictly speaking that name implies a slaty or schistose rock. The character of this hanging-wall rock is best seen at the 1,050-foot level where a cross cut drift has been driven 120 feet into this rock. A careful study of the rock was made, samples being picked off every foot of the distance along this hanging wall. It was found to be hard and compact and to show no slaty cleavage or fracture, although the original stratification lines are



VERTICAL TRANSVERSE SECTIONS OF ELKHORN MINE.

A, Across north hanging-wall body; *B*, across south hanging-wall body. Rectangular blocks represent limestone; light cross hatching represents ore extracted; heavy cross lining represents ore in place; parallel broken or dashed lines represent slate.

plainly seen. It varies from a flinty, siliceous type, carrying 94 per cent of silica and 2 per cent of lime, to very argillaceous rock practically free from lime. In the mine workings this rock shows a platy fracture, which might be taken for slaty cleavage, but which is in fact due to slight movement along the contact.

Three other hanging-wall crosscuts have been driven in the mine; one on the 300-foot level north, a short one from the 1,250-foot south stope, and one from the 1,250-foot south level. The first two were not extended far enough to pass through the slate which forms the hanging wall of the lode; but the third at a distance of 60 feet encountered a grayish-blue limestone. On the line of contact a soft clay seam occurs, which indicates faulting movement or slipping on the bedding plane. This clay carries 2 ounces of silver per ton. Somewhat higher assays were obtained from this same contact at the surface, where it is exposed in a railroad cutting, and also in a prospect shaft recently sunk. These are the only points at which this upper or second contact is exposed, but proper exploration might develop some new ore deposits on this horizon.

Foot-wall dolomite.—The dolomite or marble in which the ore occurs forms the uppermost member or stratum of the limestone series herein designated the Cemetery limestone. The foot-wall crosscuts show this rock to be of very uniform character. The bedding is rather massive, and in a crosscut driven for a distance of over 200 feet horizontally a few obscure partings or stratification planes are seen. They are marked by films of argillaceous matter, and one of them, occurring at 35 feet beneath the slate hanging wall of the ore body, is very constant in character and is commonly called the foot wall of the ore body. The argillaceous material is part of the limestone, however, and shows no clay or slickensides or other evidence of movement. The rock is a crystalline dolomite of medium and even grain, usually white, but varying to a bluish-gray or yellow color. It is so uniformly crystalline that it is properly called a marble. A partial analysis, made by H. N. Stokes in the chemical laboratory of the Geological Survey, showed the amount of magnesian carbonate to be practically the same in the different varieties from the mine.

White dolomite contains $MgCO_3$, 44.0; residue (silica, Fe_2O_3, etc.), 0.4; iron, etc., 0.3.
Blue dolomite contains $MgCO_3$, 43.7; residue (silica and iron), 1.3.
Yellow dolomite contains $MgCO_3$, 42.5; residue (silica and Fe_2O_3), 2.3; iron, etc., 1.0.

The yellow rock is the oxidized form found near the ore bodies in the upper part of the mine. It commonly shows more iron and silica than the white dolomite, and the fracture planes are marked by dendritic films of manganese.

The rock has a very pronounced granular saccharoidal texture and has been designated by the miners a sand rock, since it is sometimes so loosely cemented as to crumble, under slight pressure, to a white sand. No evidence was found to show that the dolomitization was the result either of metamorphism or of the mineralizing waters which produced ore deposition, but it is inferred that the chemical character of the rock is original, as otherwise the shrinkage in volume resulting from dolomitization would have left some evidences of such action.

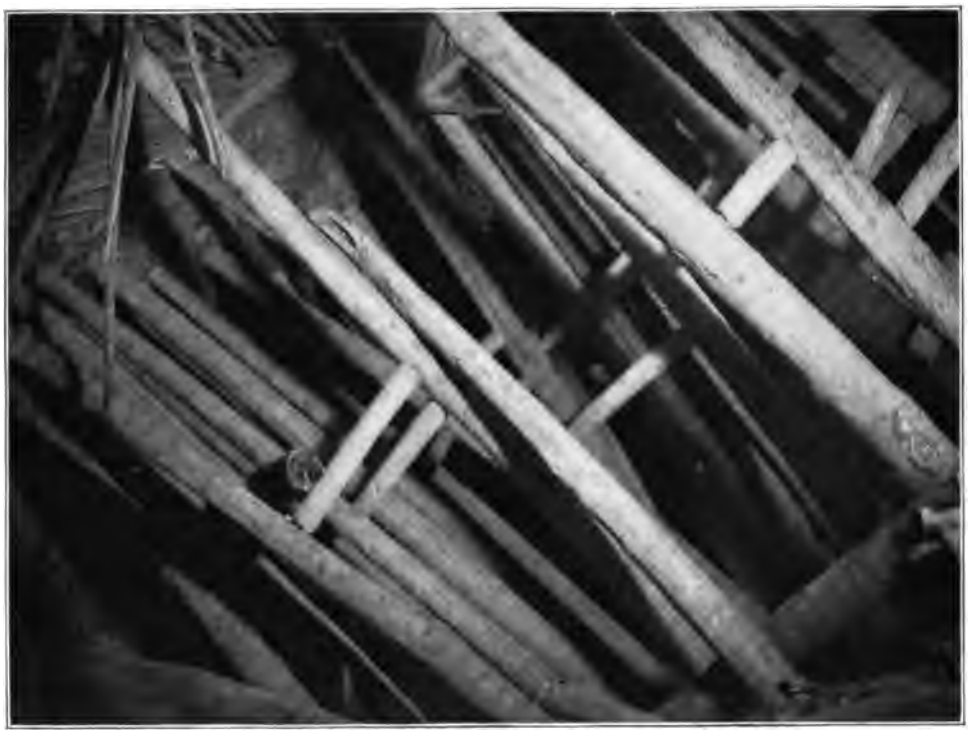
Strike and dip.—The contact on which the main ore bodies occur varies in strike, owing to the arching of the strata. Between the ore shoots it is N. 10° W., and this is very nearly the strike farther south, as shown by the prospecting levels. This conforms nearly to the general strike of the rocks near by. The levels shown on the map of the mine, Pl. LVII, follow this contact rather closely, leaving it at but few places, and then only for short distances. The levels, therefore, show very plainly the warping of the strata, and that the change in strike is not only a horizontal one, but affects the pitch of the folds as well. The changes in dip are less marked, varying from 35° to 55°. The dip of the ore body is indicated in the vertical transverse cross section of the ore body in Pl. LIV, *A* and *B*, and may also be seen in Pl. LI, where the rails on which the mine skip rests are laid parallel to the dip of the hanging-wall slate.

THE ORES.

General character.—The ores of the mine are classed as milling ores and smelting ores. The first kind are quartzose and come from the hanging-wall bodies almost entirely and embrace only those ores that can be treated in the mill. In the early history of the mine the product was entirely free milling, but as depth was obtained the ore changed in character and could be treated economically only by chloridizing roasting. The milling ore increased in baseness with depth, until at the time the mill shut down no other mill of this character was known to treat ores so base. As the natural result, the cost of treatment ran up until at the time of closing down it closely approximated the cost of treatment by the smelters.

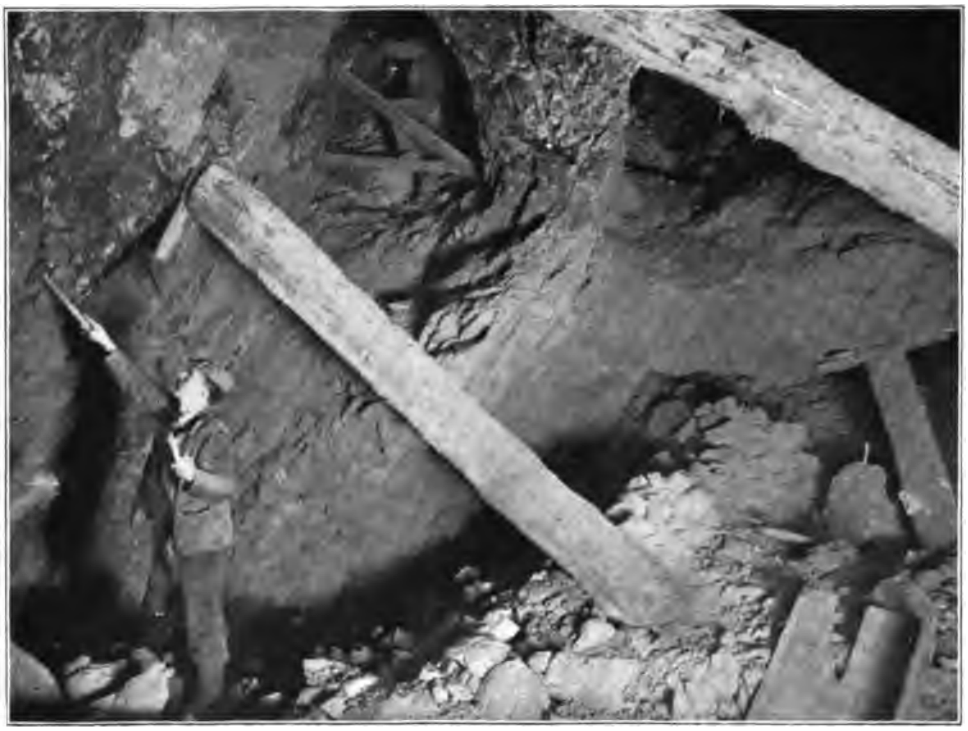
The smelting ore consists of galena, together with quartz, some zinc blende, and a lesser amount of pyrite. In the upper part of the mine these minerals were oxidized, and as a consequence the mine yielded large amounts of carbonate ore, which was sent to the smelter when it carried 20 per cent of lead. In the deeper levels and in the lower part of all the foot-wall ore bodies only sulphide ores occur, and these, when brought to the surface, contain much white limestone and were therefore cobbed by hand and sent to the smelter. No attempt was made at ore concentration, and the waste heaps of the mines contain large bodies of low-grade galena ore.

Value of the ores.—No average value can be given for the two kinds of ore for the entire mine. In 1897, 13,526 tons of ore were milled,



A. CHAMBER IN 1,250-FOOT SOUTH STOPE, ELKHORN MINE.

The timbers are 60 feet long and their closeness was necessitated by the looseness of the slate roof.



B. SOUTH END OF 950-FOOT SOUTH STOPE, ELKHORN MINE, LOOKING SOUTH.

The timbers are headed against the slate and they rest on dolomite marble. From flash-light photograph taken by C. F. Pearis

which showed an average silver content of 36.3 ounces and gold 0.0031 ounce per ton. The roasted ore has for the last three years averaged about 39 ounces of silver per ton. The shipping ore sent to the smelters averaged, during 1897, 135.4 ounces of silver and 0.152 ounce of gold per ton, with 12½ per cent of lead. At the average selling prices this gave a value of $67.78 per ton.

In the early history of the mine very much richer ores were treated. Assays of special samples show very high values. Thus, partly altered galena from the 170-foot level assayed 4,185 ounces of silver per ton. Oxidized ore, mostly massive cerussite with a little malachite, from the 1,450 foot-wall ore body assayed, per ton: Silver, 1,447 ounces; gold, 8 pennyweight; lead, 46½ per cent; copper, 5½ per cent.

Samples of the very zincky ore vary considerably in silver contents. One from the 1,750 foot-wall body, which was fairly representative, assayed 45 ounces of silver and 2 per cent of lead. A sample of the white blende contained 14 ounces of silver per ton and no lead. One of the brown zinc blende yielded 105 ounces of silver per ton and 4 per cent of lead. Another specimen containing large amounts of resinous blende and of the dark-colored blende, or "black-jack," gave 45 per cent of zinc, 3 per cent of lead, and 15 to 20 ounces of silver. In general the reddish zinc has been supposed to carry high silver values, but in the specimens whose assays are given above the silver values are probably derived largely, if not wholly, from included grains of galena. The smelter returns show that the ore shipped averaged over 20 per cent zinc, and as the penalty is 50 cents for each per cent over 12 in sulphide ore, it will be seen that the cost of treatment was materially increased. The pyritic ore, of which only small quantities have been mined, is usually low in silver. A special sample showing an admixture of galena and pyrite yielded on assay 16.59 per cent of lead, 18.59 per cent of iron, 15 per cent of zinc, with one-tenth ounce of gold per ton, and 54 ounces of silver. A sample from the 1,750 pyrite body contains 3 to 10 ounces per ton of silver. Although native silver is of common occurrence in oxidized portions of the deposit, no free gold has, so far as the writer knows, ever been found. The ratio of gold to silver in the ores is very constant and approximates 1,000 ounces of silver to 1 ounce of gold.

The bullion from the mill is commonly between 850 and 900 fine, the impurity consisting mostly of copper. For some years while the mill was running on base ore, without any special attempt at close saving, the bullion ran as low as 400 fine.

The fine particles of ore carried up in pumping the mine waters pass through settling tanks, in which the slimes are caught. These slimes have averaged over 200 ounces of silver and 4 to 5 per cent of lead, and the waste water from the cobbing house yields slimes carrying 77 ounces of silver and 4 per cent of lead. These results show the brittle character of the rich ore. Car load lots shipped in 1894 gave assays as follows:

Sulphide ore: Zinc, 32.6; silver, 180.6; gold, 0.13; lead, 14.
Oxidized silver: Zinc, 17.3; silver, 223.3; gold, 0.17; lead, 12.8.

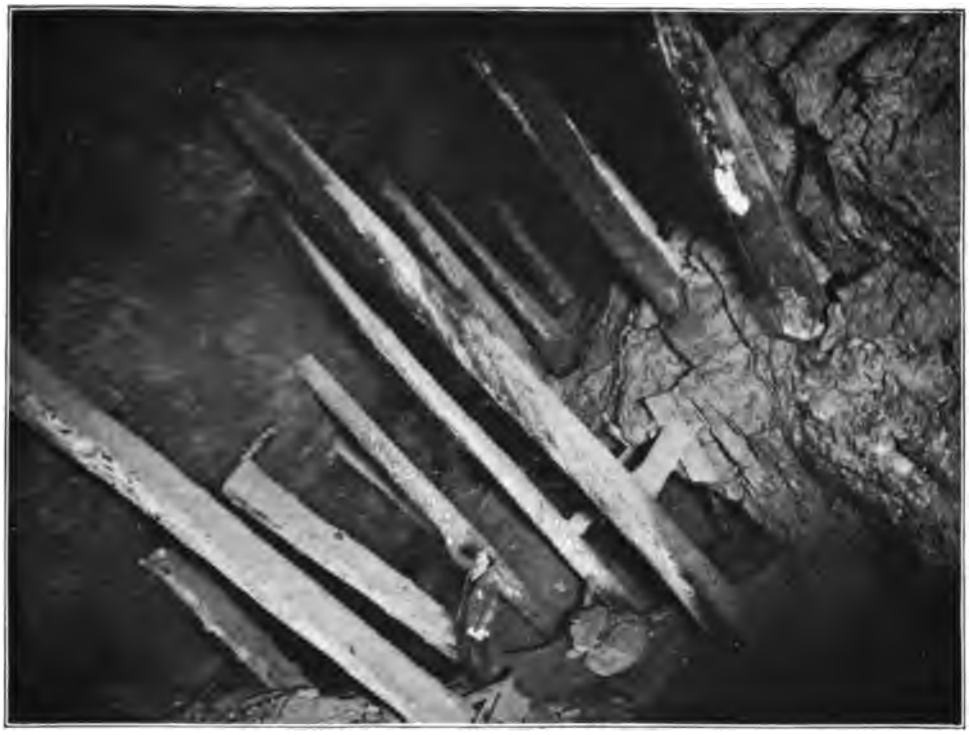
MINE WORKINGS.

The mine workings are shown on Pl. LVII, which the writer has been permitted to reproduce by the kindness of Mr. Kelley, the former manager. The main working shaft is an incline driven along the slate-dolomite contact. The incline goes down on the dip a part of the way and then bends so as to obtain an easier slope. It has an angle of 35° to 55°, the inclination varying with the undulations of the slate bedding plane that forms the roof. The roof is usually solid, and needs only upright timbers for support, caps and lagging being used in the upper part of the mine. There is no division into compartments. The ore is hoisted in a two-platform skip, on which the mine cars are run directly from the levels, as shown in Pl. LI.

In the later development of the mine, levels were driven at every hundred feet measured on the slope. These levels were run out north and south from the shaft; but owing to the nearness of the end line, the north levels are relatively short, and no prospecting has been done in that direction. On the south a number have been driven beyond the main ore body, and one (the 1,550) for a distance of nearly 2,000 feet.

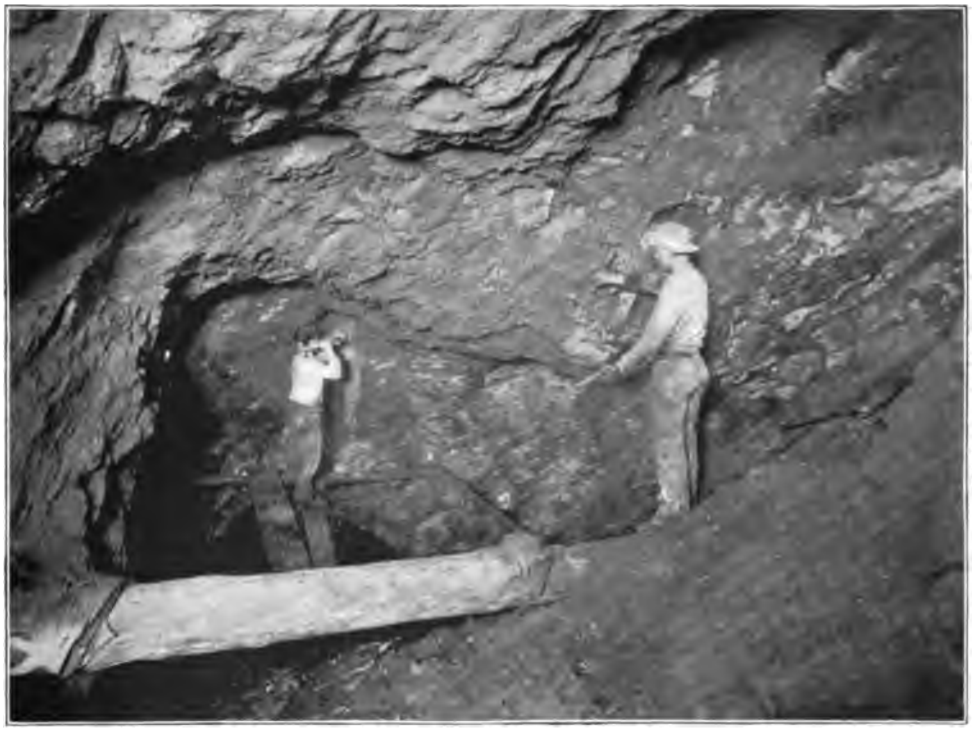
The regularity with which the main ore body maintains its position has permitted this relatively simple exploration, and as the quartzose ore bodies all come to the slate hanging wall the levels are sure to cut them. On the contrary, the chambers of silver-lead ore found in the dolomite occur without order or arrangement, and as a consequence the foot-wall crosscuts and exploration work have been very irregular. An instance of the luck of mining, and the fact that the rocks in the immediate proximity of the lead chambers show no indication of their presence, was the driving of a level past a foot-wall body, though a shell of limestone but a little over a foot thick separated it from the level.

The mine stopes are of course very irregular, owing to the extremely irregular shape of the ore bodies. They vary from small cavities a few feet across (Pl. LV, *B*), through which one can scarcely crawl, to great caverns 60 feet high. In general the hanging-wall slate needs support, as it has a tendency to shell off. Simple stulls and cap pieces were adequate in most cases (Pl. LVI, *A*), lagging being very rarely necessary. When the chambers became very large, as happens when the foot-wall bodies lie against the hanging-wall quartz, the timbering of these great caverns became a serious matter, and the few stulls at



A. THE 850-FOOT SOUTH STOPE OF THE ELKHORN MINE.

The timbers are headed against the slate and rest on the "foot-wall" streak in the dolomitic marble (the so-called sand rock). The view shows the large size of the hanging-wall main south ore shoot, at a point where the ore body extended from slate "hanging" to the foot wall. From a flash-light photograph taken by C. F. Pearis.



B. THE 1,450-FOOT STOPE IN LEAD CHAMBER.

This is an ore body entirely incased in the dolomite marble (the so-called sand rock). From a flash-light photograph taken by C. F. Pearis.

first used had to be supplemented with others until, as shown in Pl. LV, *A*, the timbers were so close one could scarcely pass between them.

ORE SHOOTS AND CHAMBERS.

GENERAL CHARACTERS.

The Elkhorn mine shows ore bodies of contrasted mineralogical character and different geological relations. The main ore channels follow the slate-dolomite contact, and as the slate invariably forms the hanging wall they are conveniently designated "hanging-wall" bodies. The ore is quartzose and is nearly all low enough in the baser metals to be milled. On the other hand, the so-called "lead chambers" or foot-wall bodies occur in the dolomite and are usually separated from the hanging-wall deposits by a greater or less thickness of that rock. The ore can not be milled, as it consists of silver-bearing galena with blende and some pyrite. This distinction of occurrence and character of ore is not invariable, since some milling ore occurs in the foot-wall bodies and some galena with the hanging-wall quartz.

MAIN ORE SHOOTS.

The occurrence of the great masses of ore constituting the hanging-wall ore shoots is best appreciated by reference to the map of the underground workings, Pl. LVII, and the transverse sections across the deposits, Pl. LIV, *A* and *B*. The mine map, being a horizontal proection, does not give a perfectly true picture of the shape and extent of the ore bodies, owing to their dip, but the data for a projection or a longitudinal section on the stratification plane of the rocks were not obtainable.

It is apparent from the map that there are two main channels of ore deposition, one to the north of the mine shaft, the other to the south, the latter being much the larger. Both are very irregular in shape, and their plan presents a striking resemblance to the maps of the famous caverns of the world. The map shows that the south ore shoot is of much greater size than that north of the shaft, and that it has somewhat more regular boundaries. Both shoots are continuous from the surface down to the 1,750-foot level, but decrease in size downward and finally pinch out. The shoots show a stringer of ore connecting them in the upper part of the mine, notably the 350 level, where the centers or axes of the two shoots are about 300 feet apart, but as the shoots diverge in depth the connection was not observed.

Forms of the ore shoots.—It is difficult to describe or even to show by figures the form of the ore shoots, since they are very irregular. Cross sections of the two shoots are given in Pl. LIV, *A* and *B*. These were prepared from the mine maps, together with sketches and measurements especially made for the purpose and compiled under the direction of Mr. William Davey, who has been in charge of the underground work ever since the property became a producing mine. As he is familiar with every foot of the mine and knows all its peculiarities the sketches are believed to have a good degree of accuracy.

The cross sections of the two ore shoots are projected from the planes shown on the mine map by red lines. These lines change in direction at several points in order to give a representative cross section of the ore body, and the points where such change is made are shown on the sections by vertical red lines.

The cross sections of the south ore shoot, shown in fig. 73, convey a better idea of the size and shape of the ore body at the two levels selected as representative of the upper and lower parts of the deposit. These sections are true cross sections, since they are projected on planes cutting the deposit at exactly a right angle to the dip. Fig. 74 illustrates the lesser irregularities of one of the smaller ore shoots.

From a study of these cross sections and the horizontal projection of the ore bodies, it is apparent that while the ore bodies are irregular in size and shape they usually lie against the bottom of the slate, and hence have a very regular roof or hanging wall; that their bottom is more irregular, but conforms in the larger bodies to a plane parallel to the hanging wall. There is a marked tending toward an elliptical cross section, the ore bodies being very much wider than they are thick, so that the greatest axis of the ellipse is parallel to the strike of the inclosing strata. The size of the ore bodies varies rapidly from place to place horizontally and on the dip. In general it is greatest in the middle depths of the mine.

Peculiarities of the hanging wall.—The contact between the slate and limestone is very sharp, and in the mine workings the

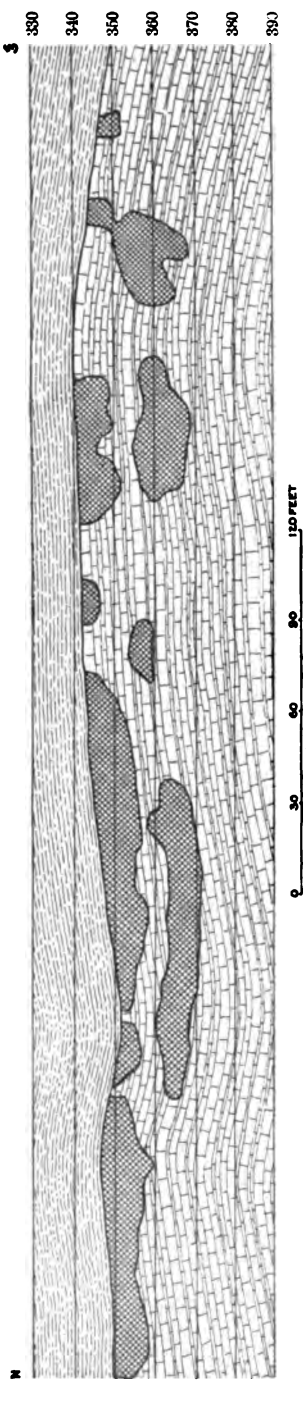
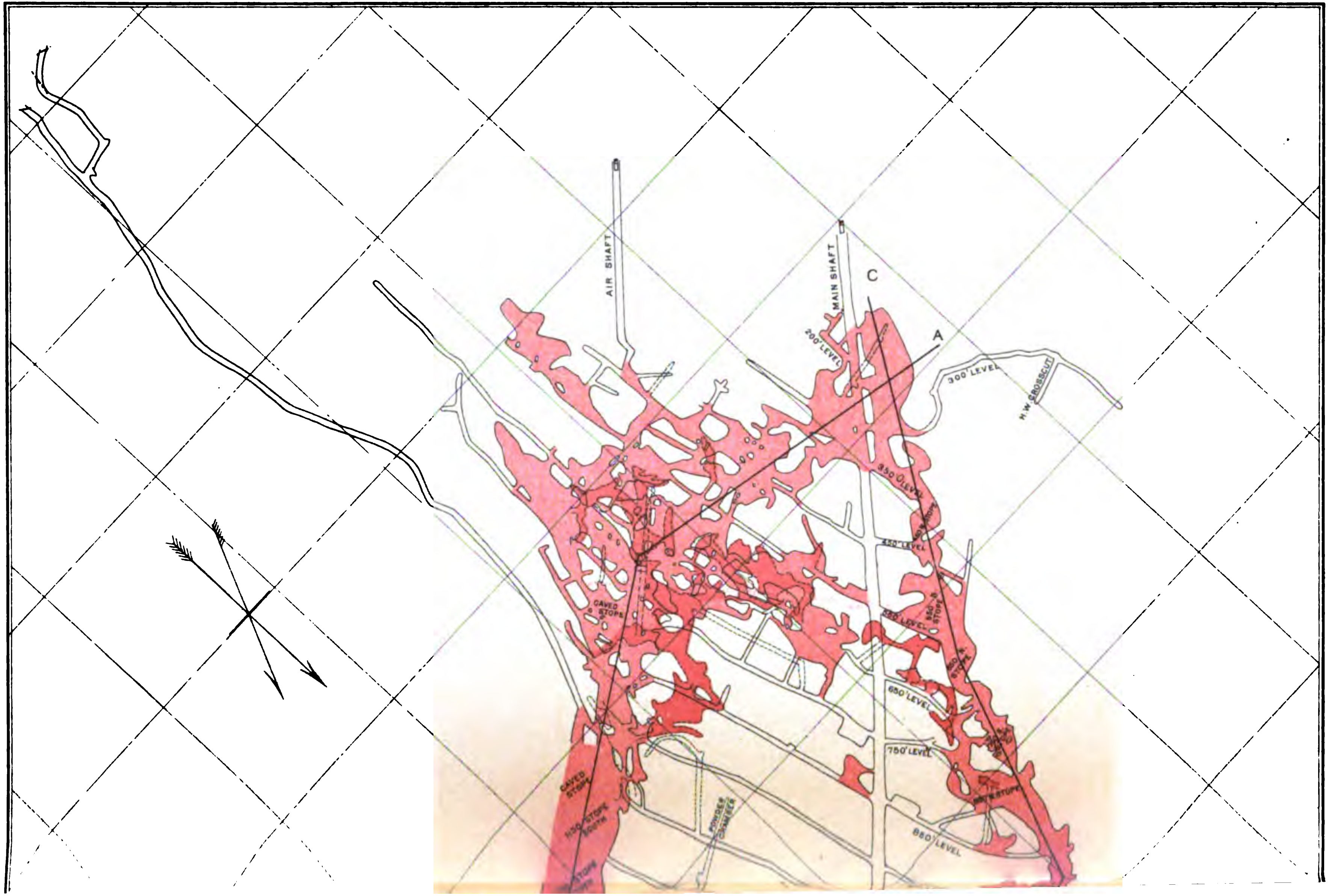
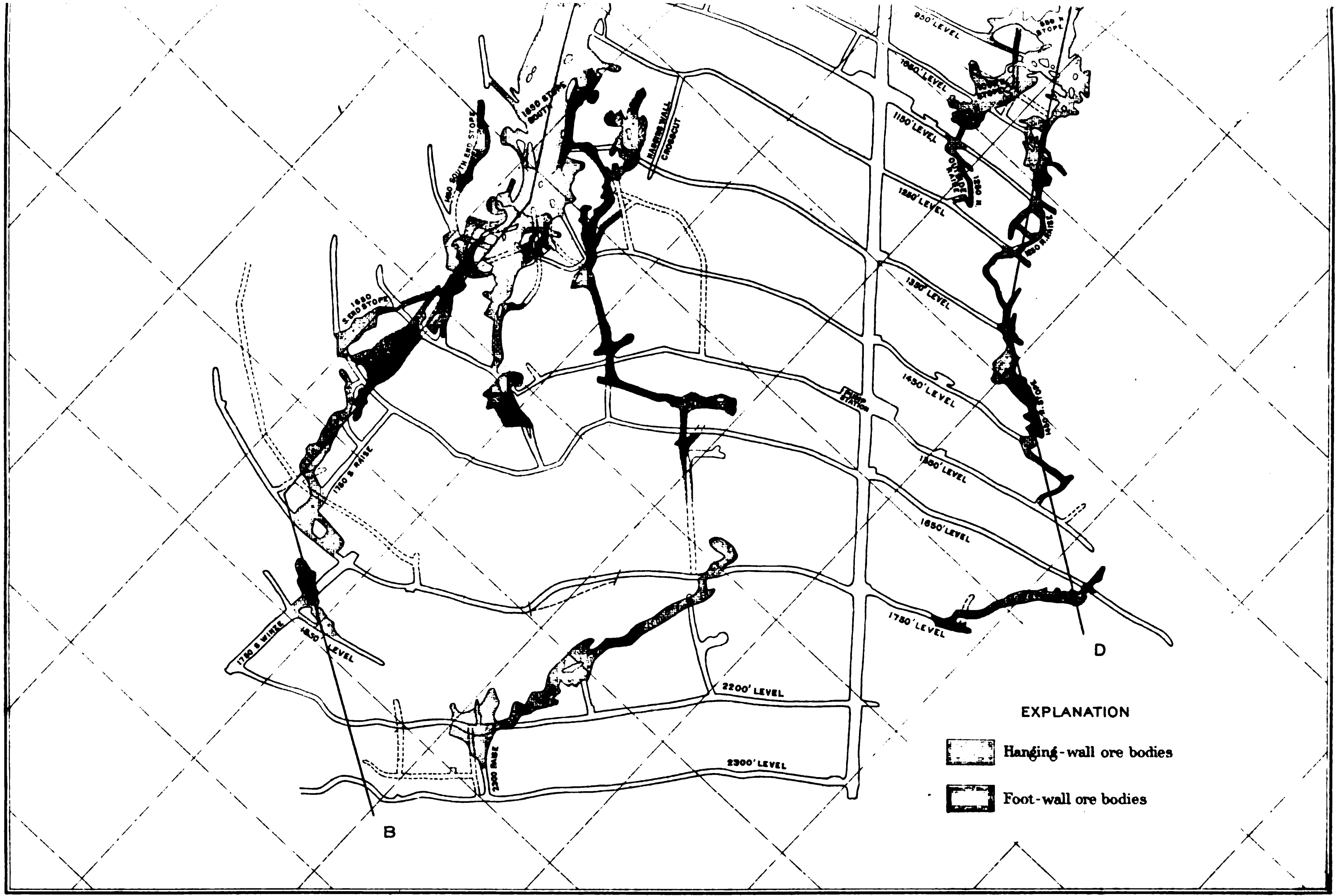


Fig. 73.—Section across the south ore body of the Elkhorn mine through the 650-foot level.


AIR SHAFT
MAIN SHAFT
C
A
200' LEVEL
300' LEVEL
N.W. CROSSCUT
350' LEVEL
450' LEVEL
550' LEVEL
550' S STOPE
650' LEVEL
750' LEVEL
850' LEVEL
CAVED STOPE
CAVED STOPE
1150' STOPE SOUTH
POWDER CHAMBER



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THE ELKHORN MINE, ELKHORN, MONTANA

Scale

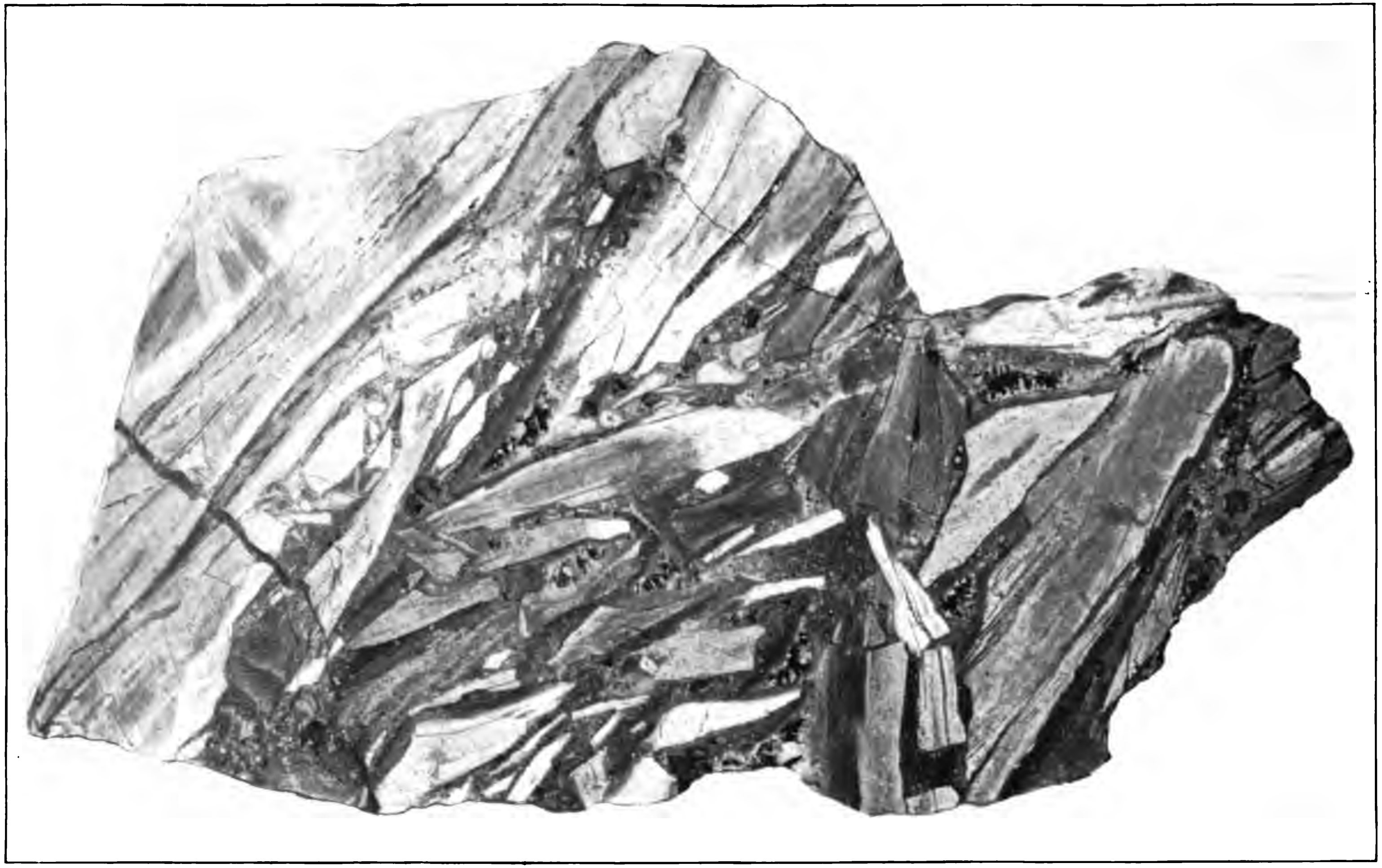
100 0 100 200 300 FEET

PLATE LVIII.

PLATE LVIII.

HANGING-WALL BRECCIA, FROM A PHOTOGRAPH.

This specimen, from the 1,800-foot level, illustrates the rather rare slate breccia found overlying some parts of the hanging-wall ore bodies. The light fragments are altered hornstones of a warm pinkish-gray tinge. Their banding is in part due to original sedimentation, and in part to secondary films of silica. The darker pieces are thoroughly pyritized. The light fragments contain considerable pyrite as a very fine dust scattered through the rocks. The arrangement of the fragments is without definite order, but adjacent pieces fit each other closely and show a movement from the bottom toward the top of the specimen. The interspaces are in part filled with gray crystalline quartz carrying pyrite and scattered grains of galena. The larger spaces between the fragments are only partly filled and show open cavities lined with projecting crystals of limpid quartz. There is also some dense cryptocrystalline quartz, which is evidently the replacement material formed by metasomatic interchange with the hornstone fragments. The galena grains, which are black in the illustration, lie in the comb quartz and are surrounded by a thin pellicle or shell of pyrite. The pyrite is determined as such by its crystalline faces. It occurs of several generations, the latest form being found on the quartz crystals lining the vugs. The specimen shows no blende, in this respect differing from material from the breccias formed of limestone fragments. Post-mineral shattering is indicated by a little veinlet of quartz which faults the shale fragments and the ore, as may be seen on the right-hand side of the specimen.



SPECIMEN OF HANGING-WALL BRECCIA WITH PYRITIC MATRIX.

slate wall is generally smooth and regular, being commonly unbroken away from the ore bodies. Above the ore bodies, however, it is frequently shaly, and gives every indication of sheeting and movement along the contact point between the slate and dolomite. (See Pl. L, *B*.) At such places it shows either a platy or a fissile parting, or more rarely a brecciation of the slate, a low-grade ore usually cementing the fragments together into a firm breccia. Instances of this were observed in the 2,200-foot level, where the roof is irregular and broken near the ore body and the ore extended 4 to 6 feet into the slate. A similar breccia was also seen near the top of the 1,850 stope, in which the fragments of shale are surrounded by a shell of fine-grained tetrahedrite, and this in turn by quartz, cementing the fragments. These minerals incrust the hanging-wall hornstone and do not penetrate it, there being no evidence of either impregnation or replacement. The workings of the 1,850 south stope show in places this hornstone breccia so softened as to be almost cheesy in consistency for a depth of a foot or more. All observations here show that the crushing is the result of the folding of the strata and the slipping and brecciation that accompanied it. Exposures in the same level (1,850 foot) north of the shaft also show evidence of a strike fault, which in this case is marked by clay selvages, and by quartz streaks. The hornstone fragments show a rude orientation, but it is clear that they formed a breccia whose open spaces are now seen filled by comb quartz and ore, as shown in the specimen illustrated in Pl. LVIII.

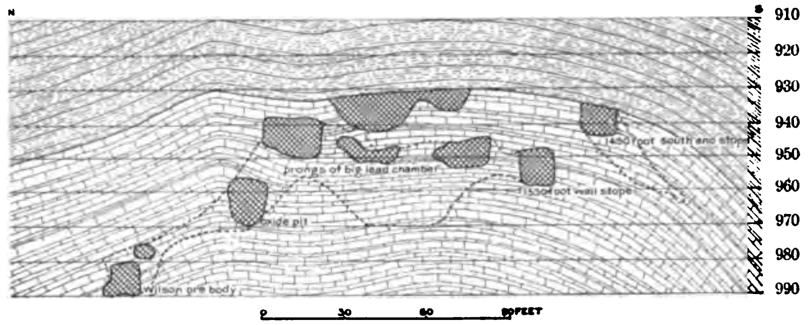


FIG. 74.—Sketch of south ore body of the Elkhorn mine on the 1450-foot level.

North ore shoot.—This ore body is much smaller than that south of the shaft. In the upper levels it is connected by a continuous mass of oxidized quartz ore with the south ore shoot, forming in fact but one ore body, but in depth it has a westerly pitch and is farther and farther away from the other ore shoot. In the upper levels the ore shoot is seen to terminate abruptly to the north against a flexure of the slate, which is particularly well shown on the 650 level. In general, however, the levels have not been extended north of the ore shoot. Followed downward the shoot bifurcates at the 950 level, the southern leg or branch rapidly pinching to a narrow pipe of low-grade ore. The main or northern branch continues downward, but also contracts in size and becomes low grade in character, but expands again between the 1,350 and 1,450 levels into a chamber-like body of lead ore. The shoot is continuous and maintains its general direction of dip and pitch to a depth of 1,650 feet, measured on the slope, where it makes an abrupt turn, pitching to the southeast. This lower part of the shoot is, however, of small cross section and the ore is extremely low in silver, so that the ore body has not been stoped below the 1,750 level. Where it crosses the shaft, about 80 feet below the level just mentioned, the shoot is 3¼ feet wide, and a few tons of ore taken out in sinking the shaft averaged 50 ounces in silver per ton. The indications point to connection between this and the 2,200 ore body shown on the map (Pl. LVII). The latter continues down to a point 25 feet below the 2,200 level, where it suddenly changes to a small mass of low-grade quartz, which, where it was cut on the 2,300 level, was but 2 feet thick and 5 feet long, and carried only a peppering of ore minerals.

South ore shoot.—This remarkable ore shoot has yielded fully two-thirds of the total product of the mine. In the upper levels it connects with the north shoot, as already noted, but assumes its individual character below the 650 level. Like the north ore shoot, it terminates against a flexure of the strata, which is most marked on the south side. A bend in the slate marks its northern limit, also, though this flexure is wanting in the upper levels, where the two shoots connect.

The south ore shoot is a continuous trunk channel from the surface down to a depth of 1,450 feet, measured on the incline, and throughout this length maintains its uniformity of cross section and dip. Below the 1,450 level the shoot varies in character and becomes smaller, but is continuously traceable and workable down to the 2,200 level. The thickness of the shoot varies from a few feet in the uppermost workings, where it will average a thickness of perhaps 8 feet of quartz, to 40 feet in the 1,350 stope. These variations are well shown in the cross section *B* of Pl. LIV.

As a rule the top of the ore body lies against the slate bedding plane. This is well shown in the cross section just mentioned, as well as in those given in figs. 73, 74, and 75. It will be seen from the section that this bedding plane, which forms the hanging wall of the ore body, shows undulations in dip, and that *the ore body is thickest beneath slight arches of the slate.* The significance of this association is mentioned later in discussing the manner of formation of the ore bodies.

The cross section (Pl. LIV, *B*) shows that the ore shoot leaves the slate between the 1,450 and 1,550 levels of the mine, but there is also a connection along the slate contact away from the plane of the section. Like the northern ore shoot, this one pinches up in one place (below the 1,650 level) and is but 8 feet in greatest diameter, but widens out below into a relatively broad mass 6 feet thick. Below the 1,850 level the ore is cut off against a slight fault in the hanging-wall slate, a branch of the ore body which was too low grade and too zincky to work, passing off to the north and into a low-grade mass of pyritic ore and nearly barren quartz. The floor or foot-wall side of the ore shoot, though less regular than the roof or hanging wall, is fairly uniform, and where the ore body is thickest corresponds to the position of a ½-inch to 2-inch argillaceous parting or bedding plane, seen in the dolomite in the foot-wall crosscuts of the mine to be of very constant occurrence.

Intermediate ore bodies.—An extension of the connected ore shoots runs a short distance downward as an intermediate ore shoot, but plays out and disappears in depth. Below the 1,750 level there is another intermediate ore body, which yielded a considerable amount of ore and which is interesting, since at this depth the ore is not oxidized and its original character may be observed. The shoot lies against the slate for the most part, but in some places is like the lower part of the south shoot, separated from the slate by a shell of dolomite. This ore body is probably formed by the coming together of the foot-wall ore shoot (marked Wilson shoot on the map) and the deflected north ore shoot which crosses the shaft below the 1,750 level. This ore shoot, as previously noted, plays out below the 2,200 level, and passes into a pipe of nearly barren quartz 2 feet thick and 5 feet long.

General character of the ore of the main ore shoots.—These great ore shoots are composed of essentially quartzose ore. The quartz, when not altered by the oxidation of the metallic sulphide in it, is usually light gray, clear or glassy, and of rather medium coarseness of crystallization; but dark-bluish, very dense, cryptocrystalline silica also occurs. As described later, there is a very marked and constant association of quartzose milling ore when the ore body lies against the slate, and of silver-lead smelting ore where the ore body lies wholly in the dolomite. This distinction is not invariable, considerable masses of quartzose ore having been found in the foot-wall ore bodies, and of galena or its decomposition products in the hanging-wall ore bodies, but the statement is true in a general way.

The ore bodies consist essentially of nearly solid quartz, mostly free from included masses of limestone or of slate. Exceptions to this occur in the 1,750 stopes, where the quartz cements limestone fragments and where the slate is brecciated and the fragments are cemented by ore. The first is less common than one would suppose. The specimen Pl. LX, *A* shows an example of this, and the slate breccia is shown in Pl. LVIII. While the mine was producing heavily only the good ore was extracted, and much low-grade ore was left in place which could have been mined at a profit before the depreciation of silver, but could not pay the cost of extraction during the last three years previous to the closing down of the property. For this reason the extent of these low-grade portions of the ore shoots and their possible connection downward through the dolomite is uncertain. The quartz ore of the hanging-wall ore shoots was more or less oxidized and free milling down to the 1,350-foot level. Below this point it steadily increased in baseness, owing to the presence of galena and tetrahedrite. In the upper parts of the ore body these minerals have been partly altered and leached out from the ore. "It is of interest to note, as the rule," says Mr. Kelley, "that the actual value of the ore itself did not diminish as depth was obtained and that the ore contains as much or more silver than that which was found at higher levels, although it was associated with a larger proportion of base metal."

Oxidation extended deeper along the hanging-wall bodies than in the foot-wall lead chambers, as the solutions naturally traveled down the slate contact. Even on the 2,300-foot level the freshly cut quartz bodies show yellow litharge spots about galena grains, and green staining of copper carbonate about particles of tetrahedrite. The pyrite is rusty and the quartz is porous about the minerals just noted. This alteration was not on a large scale, as it was in the upper levels, but it clearly shows that oxidizing waters penetrated to this depth. The ore bodies above consist mainly of oxidized ores carrying some pyrite, occasionally residual nuclei of galena, but show no definable silver minerals. These ores change in depth to those in which tetrahedrite appears, and this is undoubtedly the mineral from which the silver values have been derived in the upper part of the ore bodies. As a rule the ore shows no well-defined structure, but consists of interlocking grains without banding or crustification. Rarely there is a banding due to the replacement of limestone fragments by dark-colored jaspery quartz, the intervening space being filled with white quartz, so that the darker-colored variety is in strong contrast to it. Other notes on these characters are presented in another chapter, where the evidence showing that the ore was deposited as a replacement of dolomite is fully given. In one place where pyritic ore occurs lying against the slate the ore shows a well-marked banding parallel to the bedding plane of the slate.

In the 1,750 stopes galena was found in the quartz lying against the slate, but as a rule where galena occurs it is confined to the dolomite and is not found in quartz.

ISOLATED ORE BODIES IN THE DOLOMITE OR FOOT-WALL LEAD CHAMBERS.

Occurrence.—Besides the well-defined and continuous ore shoots of the mine which have just been described, there were a number of detached ore bodies of highly argentiferous lead ore lying encased in the dolomite. As these ore bodies occurred in the foot-wall rock and were usually separated from the slate by a greater or less thickness of dolomite, they were not developed by the mine levels run along the slate bedding plane. In general they occur close to the main ore shoot, and with one exception are found above the 2-inch argillaceous band in the dolomite, which has been called the foot wall of the ore deposit. These ore bodies are shown on the map of the mine workings by a distinctive color, but it is difficult to separate them from the hanging-wall deposit, as they often lie in the dolomite directly beneath the main ore shoot and frequently connect with these shoots. The foot-wall crosscuts and drifts of the mine are also designated on the map by separate pattern, and their irregularity is due to the fact that the prospecting for the foot-wall bodies was very largely a matter of luck and not of system. The relation of the foot-wall bodies to the main ore channels is best understood by reference to the cross sections shown on Pl. LIV and figs. 73, 74, and 75. The vertical sections do not show the true foot-wall chambers, though they do show that the main shoots become foot-wall bodies; that is to say, they are separated from the slate by a greater or less thickness of dolomite, and when this occurs there is a corresponding change in the mineralogic character of the ore. The sections shown in the figure indicated that these bodies occur beneath the main ore channels or alongside them; that they are found in the same fold or pitching arch as the ore shoots, and that, insignificant as the connecting feeder or stringer of ore sometimes appears to be, they really are a part of the same general ore mass and owe their isolation to the presence of favorable physical conditions, such as crushing of the dolomite, or to those vagaries of solutions dissolving in the limestone which are apparent on the maps of underground caverns. The difference in mineralogic character is believed to be due to a selective reaction by the dolomite, whereby lead-silver ores are deposited when ore channels penetrate limestone, and is in accord with observations of ore deposits the world over.

When the ore is removed from these bodies great spaces are left which might readily suggest that they represent cavern deposits, but this name is misleading, as it implies an origin by cavern filling either partial or complete. Projecting fingers of the deposit form short pipes of ore, but although water courses exist in the dolomite and are often traceable for hundreds of feet, no such pipe of lead ore exists in the mine, and this is of itself evidence that the ore bodies originate by replacement. The form of the ore bodies is very irregular; they commonly show rounded sides with projecting points and fingers, and such projections are more apt to mark the upward extension of the ore body along the dip than either its downward or its lateral limits.

In general these foot-wall bodies are extremely irregular. There seems to be a tendency for them to be limited by the so-called foot wall, which is a thin seam of argillaceous limestone from ¼ inch to 2 inches in thickness, occurring at a distance of about 35 to 50 feet from the hanging wall. This occurrence is shown in the vertical cross sections represented on Pl. LIV, *A* and *B*, and in the sections across the ore shoots shown on figs. 73, 74, and 75. The significance of this foot wall lies in the fact that, owing to its argillaceous character, it would limit replacement of the limestone and therefore form a somewhat regular foot wall to these lead chambers. The roof of the foot-wall bodies is irregular, and no definite limit has been found. In the dolomite, prongs and fingers extend out from the main body in various directions, giving an extremely irregular profile when they are seen in cross

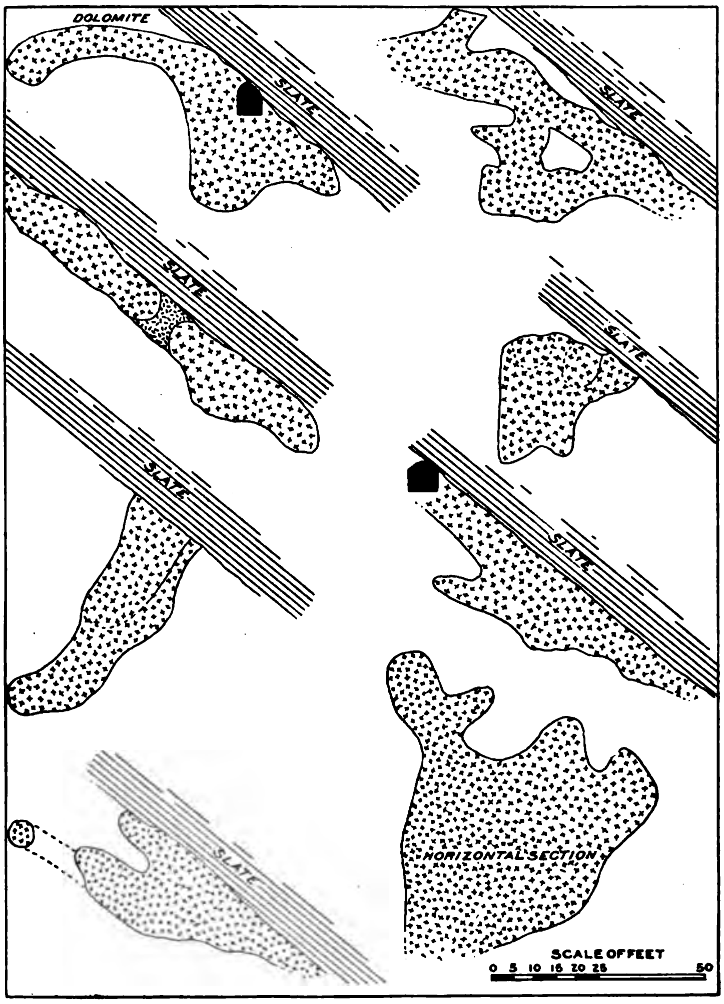


FIG. 75.—Section across the 2,200 ore body of the Elkhorn mine, showing typical forms of replacement deposit.

PLATE LIX.

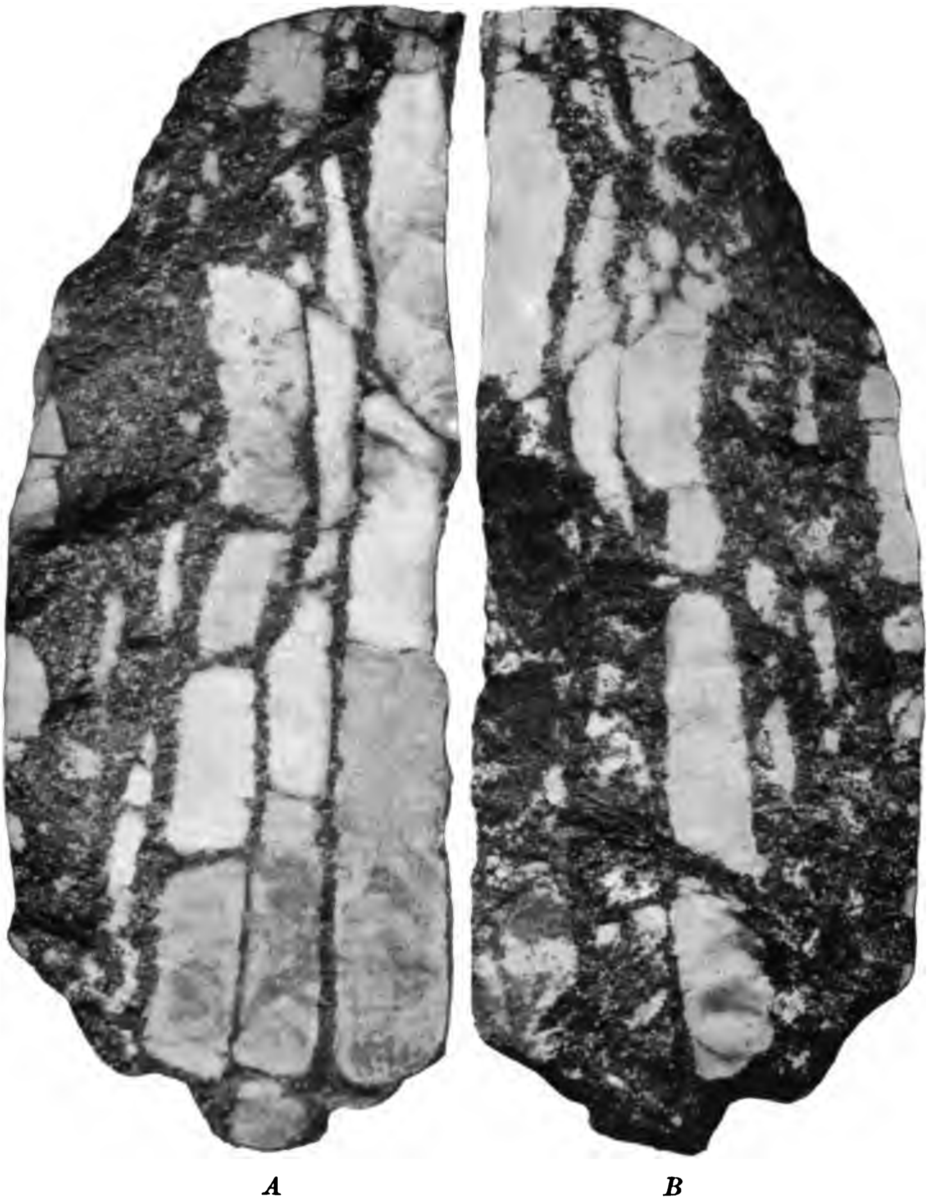
PLATE LIX.

SLAB OF ORE FROM THE WILSON SHOOT.

This plate shows photographs, on a reduced scale, of both sides of a slab of ore from the Wilson ore shoot. The white areas are the white dolomite sand rock and the dark areas are ore consisting of galena, yellow blende, and a very little pyrite.

A shows the dolomite fractured into slabs by parallel planes and the slabs broken into rectangular blocks by cross fractures, which, as a rule, do not extend through more than one slab. In the lower part of the specimen replacement has gone far enough to obliterate the rocks, and only nucleal masses of limestone are seen. In the upper part the fractures contain galena and blende, which has penetrated along the minutest cracks and by replacement has enlarged the opening and formed the layers seen.

B shows the reversed side of the same specimen, which is a slab about an inch thick. In this specimen the lower blocks of white dolomite which are so conspicuous on the first figure are almost completely replaced. The specimen shows that little cracks extend into the blocks of white dolomite, and that replacement takes place rapidly in the interior of the mass and not alone from the outside, so that while the corners are rounded and progressive replacement is shown along the borders the interior is attacked until only a sponge is left of the white dolomite.



GALENA ORE, SHOWING LIMESTONE BRECCIA CEMENTED BY ORE

section. The sections shown in Pl. LIV are typical for these foot-wall bodies, though they actually represent the 2,200-level hanging-wall ore shoot. These foot-wall bodies invariably show a connection at some point with the main ore-body ore channels. These connections are strings of galena ore passing into a mixture of galena and quartz, and this into purely quartz ore connecting with the hanging-wall quartz body.

Filling.—The ore forming these lead chambers is not a solid mass of galena or its alteration products, but consists of a breccia of white or yellow dolomite fragments cemented by ore (Pl. LIX). Sometimes the upper part is a limestone breccia with the interspaces filled with blue quartz, in which case the quartz carries from 50 to 100 ounces of silver, though it may show no recognizable minerals. Such ore carries no lead, but when broken down is low grade and will run but 15 ounces of silver per ton. In the upper lead chambers the higher parts of the ore bodies were oxidized to lead carbonates, showing a slight coloration from copper carbonates. Very often, also, there was a quartz crust found as a shell about certain parts of the ore body, usually near the top. In general, however, the lead ores are limited abruptly by limestone, or by low-grade ore from which strings and fingers of the galena and zinc extend out into cracks of the white limestone. No foot-wall bodies have ever been found in the mine above the 550-foot level.

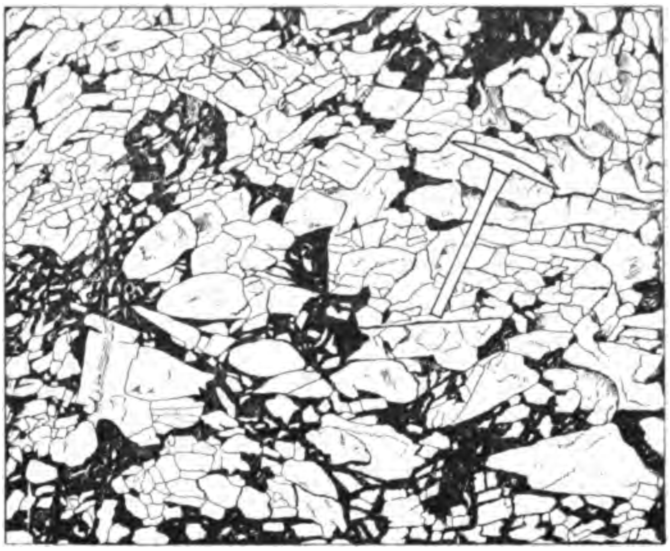
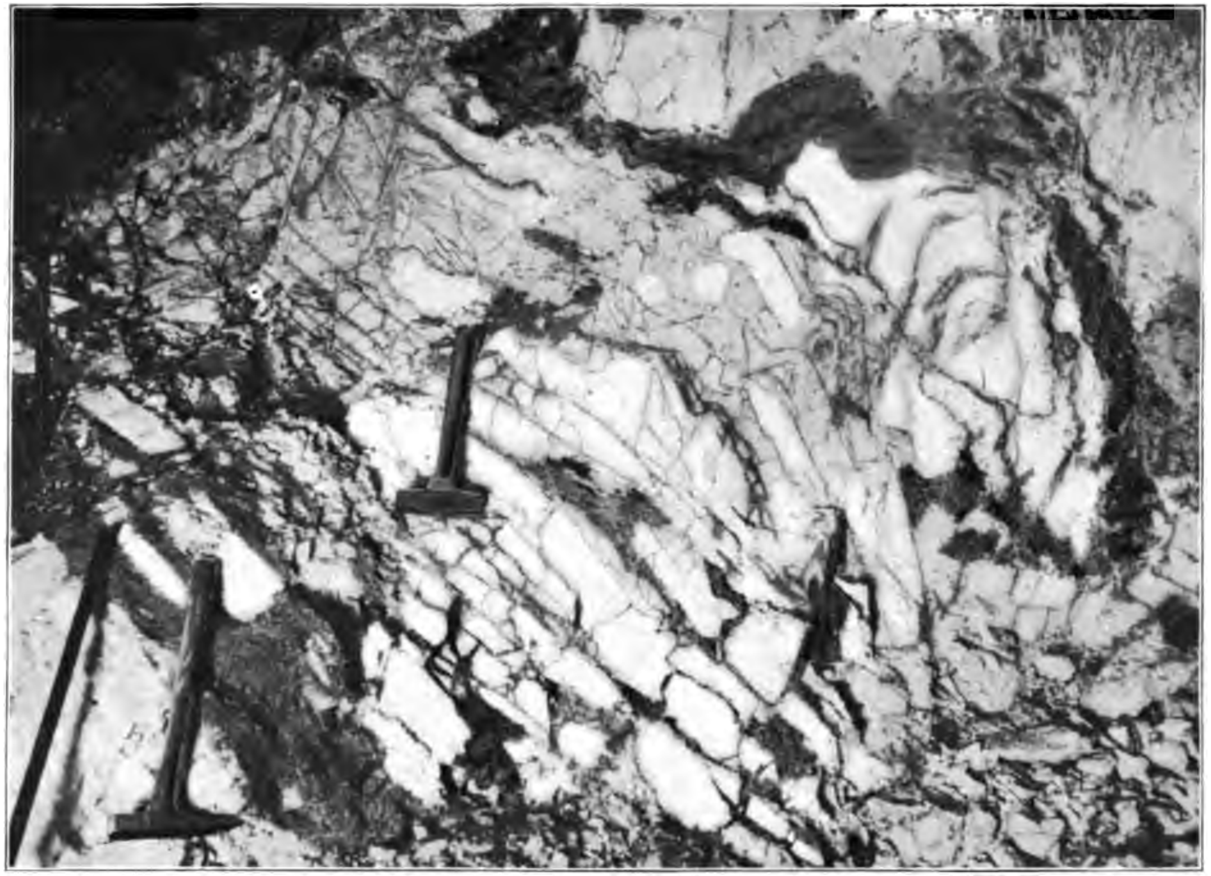


FIG. 76.—Face of Wilson ore body, 1,450-foot level stopes of Elkhorn mine.

An exposure showing the typical character of the filling of these foot-wall chambers is shown in Pl. LX, made from a flash-light photograph taken by Mr. C. F. Pearis. The actual face illustrated was in the 1,750-level intermediate stope. The view shows that the limestone blocks are in part angular and in part rounded, and though positive proof that the ore is formed by the replacement of limestone is afforded by underground workings, by numerous specimens, and by thin sections of the ore seen under the microscope, part of the ore body appears to be due to the filling of the open spaces between the limestone fragments. Any marked solvent action would have rounded off the sharp angles and destroyed the long, thin slivers of limestone which are shown in the picture. Another face shown in fig. 76 which is a direct reproduction of another flash-light photograph taken by Mr. Pearis, shows broken limestone which in the lower part of the view is a breccia and in the upper part has been flexed and crushed sufficiently for the solutions to penetrate along the fractures, cementing the pieces together. There is evidence in the arrangement of the limestone blocks, not only of the tearing apart of the limestone in parallel plates, but also of movement along the fractures by which these blocks are twisted and their orientation destroyed.

Description of a foot-wall ore body.—Most of the foot-wall bodies were practically mined out at the time of the writer's visit, the ore that was left being found along the sides of the ore bodies or in small projecting prongs of the main chambers. A good opportunity for an examination of an ore body of this kind was, however, afforded by the opening up and extraction of an ore body lying between the two main ore shoots. This ore body has been called the Wilson shoot, and lies in the dolomite between the south ore shoot and the main shaft. This body, unlike foot-wall bodies in general, is not directly behind or underneath the main ore shoot, but lies off to one side and at a greater distance from the slate contact than most of the foot-wall bodies. Its general characters, however, are similar, though it contains a larger proportion of quartzose ore. The ore body begins as a spur of the main south ore shoot near the 1,250-foot level. This spur passes off into the foot-wall dolomite as a pipe or chimney and opens out into a broad and high chamber, from which large amounts of ore were extracted. It forms a continuous, though irregular, ore body from a point below the 1,250-foot level to a short distance below the 1,650 level; its farther extension is uncertain, as the ore at that point was too base to mine, though it lies directly over the upper part of another ore body and probably connects with it by low-grade ore. Its location corresponds to a decided bend in the strata, which develops into small cross faults throwing the slate hanging wall in the 650 and lower levels. These faults are apparent in the slate, but are dissipated in the limestone in a series of parallel fractures or in a simple crushing of the rock. The connection with the main south ore shoot shows porous and oxidized quartz, which changes in the limestone to oxidized lead ore consisting of cerussite and other products of decomposition carrying high values in silver. This character of ore continues



ORE BRECCIA, 1,650-FOOT SOUTH FOOT WALL ORE BODY (LEAD CHAMBER), IN DOLOMITE.

Looking south toward foot walls. The white areas are blocks of unreplaced dolomite. The dark areas represent ore (galena, etc.) filling cracks between fragments and replacing them. From flash-light photograph taken by C. F. Pearis

downward to the 1,400-foot level, the silver contents being very uniform except on the borders of the deposit, where it becomes lower in grade. This decomposed ore contained nucleal masses of sulphides in the upper part and changes to a solid body of galena with blende and pyrite about 200 feet below the top. The sulphide ore continued downward, but decreased gradually in silver contents, corresponding to a decrease in amount of galena and a larger amount of zinc and pyrite, until finally, at a point 10 to 15 feet below the 650 level, the ore consisted largely of black-jack (blende) with iron pyrite, and carried from 10 to 15 ounces of silver per ton. The big ore chamber consisted mainly of shipping ore of the character just noted, the upper 6 feet, however, being a rich oxide ore that was taken off for milling, and rich bunches and streaks of this ore were found along fracture planes extending into the limestone above the ore body. Oxidation had also extended a short distance down the sides of the ore body, altering the outer portion of the ore and the limestone adjacent to it. The top of the main chamber of the shoot differed somewhat from this in showing a clean roof of white dolomite sand-rock devoid of any rust, stain, or other evidence of oxidation, and the quartz found near the top of the ore body was white and vitreous. In the north prong of this big chamber there was some oxidation, the dolomite being yellow with dendritic manganese markings and the quartz carrying some oxides.

The rich oxide ore, which, as just noted, was taken off for milling, lay against the roof of the ore body and rested upon the shipping ore of the foot-wall side. The quartz was brown and watery looking, and apparently carried no values, though it assayed 75 ounces in silver and formed a very good milling ore. Underneath the altered lead ores there was usually more or less sulphide ore, which averaged over 200 ounces in silver per ton. The pyritic ore, into which the ore shoot passed in depth, varied greatly in value. This no doubt depended somewhat upon the proportion of galena which it contained, but also consisted in a variation in the silver contents of the pyrite itself. The size of these foot-wall workings is often somewhat larger than that of the actual ore body, since strings of rich galena extend out into the limestone, particularly where the ore body wedges out at the sides and ends. This is well shown in the lower end of the 1,650 foot-wall stope, where the ore body is 4 feet high in the lower part, with vertical side walls showing no stringers of ore running into them. At the lower end, where the ore ends in a pocket, the limestone overlying it shows streaks and films running out into the yellow dolomite forming the roof. Commonly the yellow color of the dolomite is an indication of the proximity of ore bodies, as it is due to oxidation following down the borders of the ore shoots, and it is said to have marked the occurrence of the richest galena. As an exception to this, it should be noted that in the 2,200 stopes the ore found in the white limestone and associated with the white quartz was the richest ore. This, however, is explained by the occurrence of tetrahedrite in the ore. In general it may be stated that in all the ore bodies the proportion of pyrite increases in the lower part, and in some cases the low values of this pyrite prevented a thorough exploration of the ore body, so that its actual limits and lower extensions are not definitely known. However, fairly thorough prospecting on the 2,300 south levels has demonstrated that the ore bodies have pinched out at that depth and that no large masses of payable ore occur.

Considerable space has been devoted to a description of the foot-wall bodies, as it is believed that they are merely parts of the main ore shoots and show in the structure evidence of the manner of formation of the deposit. In the lead chambers the limestone has been replaced mainly by galena; in the main ore shoots, by quartz carrying tetrahedrite.

NATURE OF THE ORE DEPOSIT.

STRUCTURAL RELATIONS OF THE ORE SHOOTS.

An examination of the mine map shows a very interesting connection between the occurrence of the ore shoots and the presence of flexures in the strata. With rare exceptions the mine levels are driven along the slate-limestone contact. The map therefore shows horizontal sections of the contact planes, and the curves in the levels correspond to flexures in the rocks. It is apparent from the mine map that the strata are bent by two flexures whose arc is longest in the deeper levels. The flexures are farthest apart in the deep levels and approach each other in the upper levels, until they form practically one fold. The diagram (fig. 77) which is made from the mine map, shows that the ore occurs on the under side of steeply pitching arches; that is, underneath flexures in the hanging-wall slate. This may be regarded as definite proof that the ore-bearing solutions came from below and followed up channels formed by the crushed limestone and confined by the impervious hanging-wall slate. This proof is the more interesting because of the gradual impoverishment of the ore shoots in depth and their pinching out in the deeper workings. The material for the ore shoots must have come through fissures now filled with low-grade or barren quartz, such as the small ore shoot of the 2,300 level. The ore of the hanging-wall bodies was in part a breccia and in part a solid ore. It is certain, however, from the occurrence of the

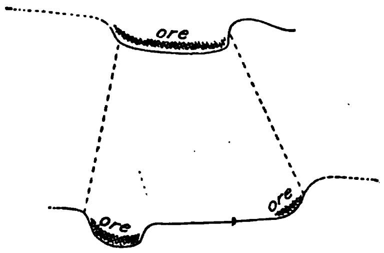


FIG. 77.—Diagram showing occurrence of ore shoots in pitching arches or folds of the strata, Elkhorn mine.

ore shoots that ore deposition was practically controlled by the rock flexures, and the ore bodies are thickest where undulations in the slate occur, as shown in the vertical cross sections. In a lesser degree the minor fractures also affect ore deposition.

In order to show the relation of the ore bodies to the folding of the rocks a section has been prepared across the ore bodies of the 1,450 level. The plane of the section is not a horizontal one, but has been made perpendicular to the hanging wall in order to give a true cross section of the ore body. The figure shows a very marked bend in the hanging-wall slate, and the ore bodies cut are only parts of a very much larger chamber indicated by the dotted lines. A similar section (fig. 73, p. 478) made parallel to the drift and perpendicular to the hanging wall on the 650 level, shows the ore body south of the shaft. In this case the position of the foot-wall bodies relative to the hanging-wall ore shoot is plainly indicated. The plane of the section cutting across projecting arms of the hanging-wall ore body does not show a continuous mass of quartz along the ore contact, although the bodies seen in the figure would show such connection if cut by planes either above or below that actually used. On this figure no attempt has been made to indicate the actual extent of the ore bodies in other planes.

South of the shaft the flexure in whose axis the main ore shoot is found is accompanied by several small cross faults, and these faults have affected ore deposition. On the 1,850-foot level there is undoubted evidence of a strike fault, and the ore is connected with and comes against this fault. In passing down the winze below the 1,850-foot level the strike fault is seen to turn downward and become nearly vertical, and is accompanied by a cutting off of the ore. It looks as if the ore deposition was controlled by the open spaces formed by slipping along a step fault in which the tearing off or projecting corners furnished a breccia which filled in the angles and was the seat of ore deposition. If this theory is correct, ore should be found wherever a fault changes its inclination from vertical to an angle corresponding to that of the hanging wall.

ORE SHOOTS CONSTITUTE SADDLE DEPOSITS.

The Elkhorn ore bodies are saddle deposits formed in pitching arches beneath a bed of impervious slate and in a dolomite marble. Lying along the bedding plane between the dolomite and slate, it would commonly be called a "contact deposit," but, as pointed out by Emmons,[1] this is a term that should properly be confined to the contact between igneous and sedimentary rocks—that is, between rocks not of contemporaneous origin. The term "bedding-plane deposits," though somewhat clumsy, is preferable to "bedded vein," since the latter seems to imply horizontality and possibly synchronous formation with that of the inclosing strata. In the disturbed strata of the Elkhorn district the folding has been accompanied by movement or slipping along the bedding planes, and this movement has produced brecciation and minor faulting along the axes of the lesser folds. The impervious slate acts as a cover that confined the circulating waters to the pipes of crushed rock in the saddle of the arches. Similar contact deposits between slate and limestone are relatively common in the Rocky Mountains, and may be ascribed to the impervious and insoluble nature of the slates and perhaps to the fact that precipitation was induced by the retardation of the current along the confining wall. As already stated, it is only when the slate is brecciated that ore deposition has taken place in this rock, the deposits generally being confined to the dolomite.

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[1] Structural relations of ore deposits: Trans. Am. Inst. Min. Eng., Feb., 1888, pp. 10, 14.

That actual movement has occurred along the slate and limestone bedding plane is proved by the platy nature of the strata at their contact, as well as by the brecciation of both slate and limestone in the folds. That this movement was not general, and hence that the bedding plane was not the site of a strike fault or fissure, is shown by the localization of the brecciated material and of the slips coincident with the folds. On the other hand, the ore channels occur in the saddles of the folds, and it is evident that folds formed under a relatively light load would tend to develop open spaces in the saddles. Where a soft stratum, such as shale, occurs between hard bodies there is a tendency for the soft rock to flow into and fill such a cavity, forming a saddle-shaped mass, thick on top of the fold and very thin on the shanks. In the Elkhorn deposits, however, the hornstone (called slate by miners) yielded to flexure and formed a generally unbroken, impervious roof; though metamorphosed, it resisted crushing better than the underlying brittle and friable dolomite, so that the latter was crushed and shattered and formed a loose breccia under the arches. As the general rock folding of the sedimentary strata occurred before the igneous rocks were intruded, and hence before rock metamorphism took place, it is necessary to suppose a later period or periods of folding in which the convolutions in which the ore deposits occurred are supposed to be due to the thrust of the later igneous intrusions.

In its brecciated character the deposit is analogous to the silver-lead deposits of Eureka, Nev. Interstices between the fragments of crushed limestone would admit of a relatively free passage of surrounding waters, and would furnish space for the precipitation of quartz and the ore minerals, while the readily soluble dolomite fragments would be replaced by vein material. The irregular forms of such ore bodies are to be explained by the occurrence of crushed masses of rock and by the dissolving action of the mineralizing solutions.

The Elkhorn deposit is noteworthy for several reasons:

First. It occurs in plicated sedimentary rocks metamorphosed by a succession of igneous intrusions.

Second. It occurs in the crushed rock found in the saddle of minor folds, and follows the bedding plane of an overlying altered shale (hornstone). The crushed rock formed the primary ore channel for uprising siliceous waters.

Third. The deposits are not the result of the filling of preexisting caves in the limestone, but are mainly due to gradual replacement of dolomite by the substances brought in by ore-bearing solutions. The ore is confined almost entirely to the more readily soluble dolomite, when found in the hornstone being only a cementing material for fragments of that rock.

Fourth. The ore is believed to be derived from below, because it occurs on the underside of an impervious stratum, bent in pitching anticlinal folds.

Fifth. That the ore decreases in amount and richness in depth is no objection to the theory proposed, since it is now well known that in the Black Hills the barren, or but slightly mineralized, "verticals" (mere cracks traversing the rock) are the feeding channels for important ore bodies that occur in readily replaceable rocks, particularly at bedding-plane contacts with adjacent impermeable strata.

ALTERATION OF COUNTRY ROCK.

The rock adjacent to the ore deposits shows none of that marked alteration characteristic of ore deposits in igneous rocks. The dolomite is not the result of the dolomitization of a limestone by solutions ascending through the ore channels, since it maintains its character remote from the ore. The hanging-wall slate is usually slightly altered for a few inches from the ore bodies, and where the rock is brecciated and the fragments are cemented by metallic sulphides the rock has been decomposed and even pyritized. The dolomite does not show alteration from the ore-depositing solutions. This is lacking because the action was one of replacement of dolomite by silica and sulphides. In this sense the rock is altered, for near the ore bodies it is shattered or crackled and the fractures are filled by silica. These silica films are due primarily to a penetration of the solution along the fractures, but they are more properly replacement deposits, since their sections studied under the microscope show that the dolomite is attacked along cleavage lines, etching and deposition of silica going on simultaneously. This is, of course, merely a phase of the process of ore deposition, for the quartz films often carry sulphides, and if the dolomite be dissolved away by dilute acid a skeleton is left, composed of silica and metallic sulphides, which constitutes a cellular mass pseudomorphic after the dissolved fragments. Where oxidation of the sulphides has produced acid waters this same action has taken place in nature. Where substitution has gone still further, and the original solutions have replaced a large proportion of the limestone, the original brecciated character is lost, and a mass of quartz, or ore, carrying included fragments of limestone is all that is left to indicate that the process was one of replacement.

MODE OF FORMATION OF ORES.

ORIGIN BY REPLACEMENT.

That the ores are deposited from aqueous solutions there can be no doubt; their general occurrence, mineralogic character, and a study under the microscope of thin sections all confirm this conclusion, and as such origin is now generally accepted for most ore deposits no further comment need be made on this subject. That the ores were deposited by ascending waters is proved, as has already been stated, by their occurrence under pitching arches. That the ores are deposited by replacement of country rock, and only to a minor degree by the filling of the interspaces between limestone fragments, is proved by the evidence afforded by a study of the ore deposits, by the ores themselves as seen in hand specimens, and by thin sections examined under the microscope. By replacement is meant what is technically called metasomatism; that is, interchange of substance. It differs from pseudomorphism, as the latter implies preservation of the form of the matter replaced, while metasomatism does not involve the preservation of either form or substance.

The positive evidence of metasomatism is very striking and complete at Elkhorn. In the foot-wall ore bodies especially, the structures—which are represented in the plates made from photographs of actual ore faces—show that masses of crushed dolomite resulted from folding, and the open space between the fragments, if such existed, would, if filled by ore, produce the ore breccia now seen. A careful study of all the cavities left by the extraction of ore showed that no preexisting caves served as loci for ore deposition. Moreover, the ore bodies as mined never showed open cavities above the ore. Hand specimens, as for instance the one of which photographs are reproduced in Pl. LXI, show little dolomite blocks in various stages of replacement. In the quartz ores every stage may be seen, from little films of silica penetrating the shattered limestone along capillary fractures to a mass of quartz containing nuclei of limestone. It should be noted also that the ore shows no crustification.

The dolomite adjacent to the ore bodies is netted with films of silica which are often extremely thin. The silica occupies fissures which are evidently the result of a shattering of the rocks in place, without disturbance of the fragments. Where the silica carries no metallic

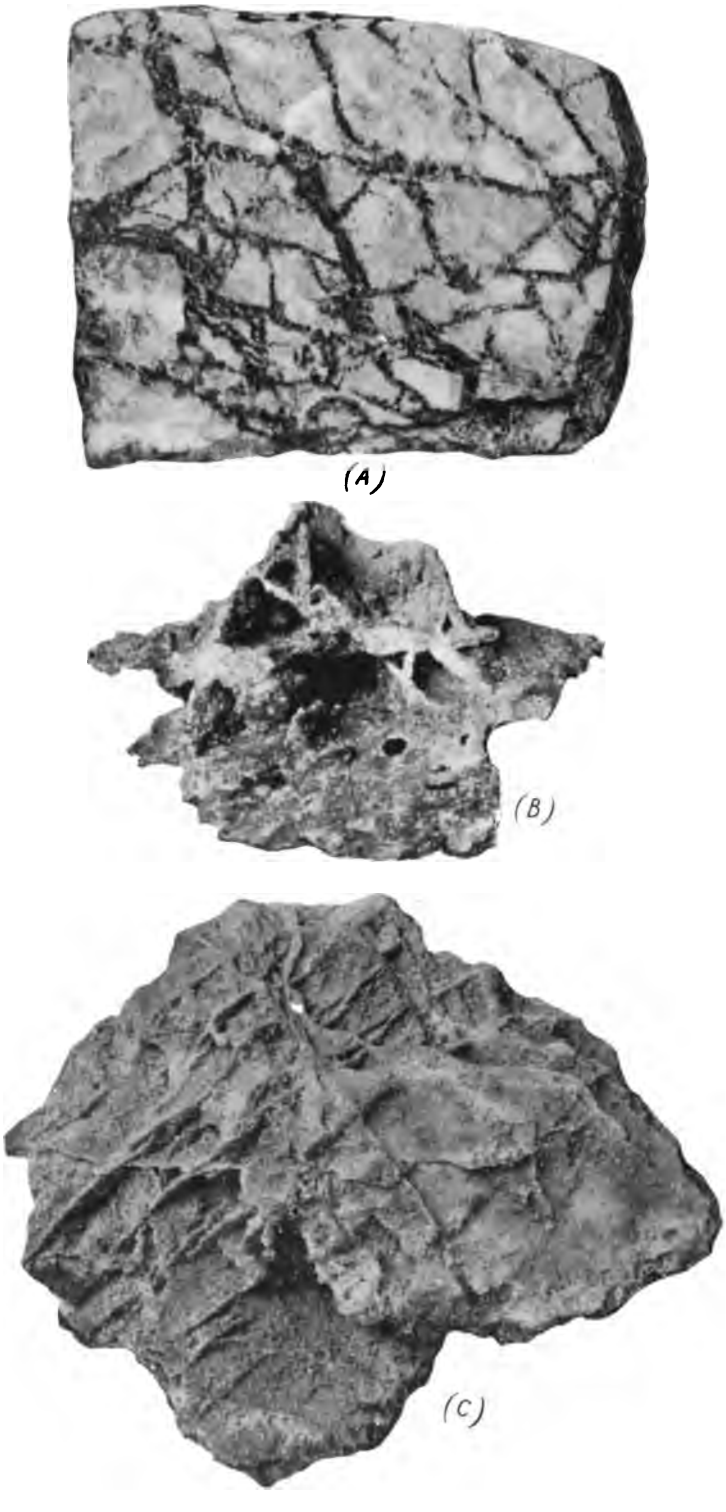
PLATE LXI.

PLATE LXI.

LIMESTONE FRAGMENTS CEMENTED BY QUARTZ.

The photograph shows a specimen (*A*), natural size, of limestone fragments cemented by dark-blue quartz. The fragments fit together so closely that it is evident that no movement has taken place, but that the brecciation is the result of a shattering of the rock with the infiltration of siliceous waters and replacement along the cracks. The quartz carries good silver values, though the ore particles are too minute for determination of species. The quartz is extremely finely granular, showing the texture and color characteristic of metasomatic replacement, and not the comb structure of the filling of open cavities. The specimen illustrates an earlier stage in the formation of the quartzose ore of the hanging-wall ore shoots.

Other specimens (*B* and *C*) show progressive stages in which the small fragments are replaced and the quartz seams are enlarged by the rounding off of corners, and still others in which only residual masses of limestone occur scattered through a massive quartz.



LIMESTONE FRAGMENTS CEMENTED BY QUARTZ.

sometimes pyrite grains occur abundantly dotting the dolomite parallel to the fissure wall, and in such cases the quartz carries no pyrite, or else is simply dark colored, owing to a dust of minute particles of the iron sulphide. More commonly the quartz is seen replacing the dolomite, both as well-marked fissures and as grains which are apparently interstitial, presenting the appearance of an open sponge of dolomite filled by quartz. In this case, however, the relation of the crystalline outlines of the quartz to the dolomite grains and the penetration of the latter by the quartz show clearly that the silica has replaced the former mineral. In general the quartz replacing the dolomite shows a finely crystalline character. Oftentimes fragments of the carbonate are surrounded by a band of dense, cryptocrystalline quartz which is of the character supposed to be typical of replacement.[1]

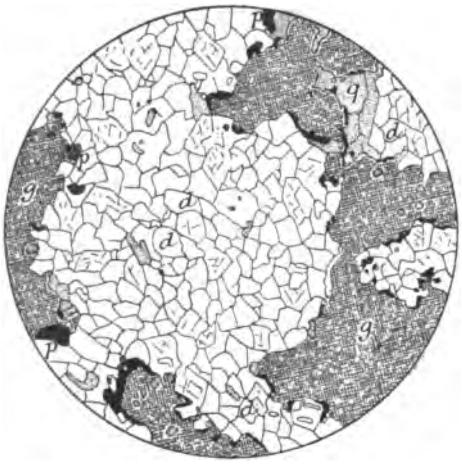


FIG. 78.—Thin section of ore showing replacement of dolomite by galena (after Lindgren). *g*, galena; *p*, pyrite; *d*, dolomite; *q*, quartz, secondary. Magnified 15 diameters.

More often this cryptocrystalline quartz is subordinate in amount or entirely wanting, and the main body of that mineral presents the somewhat coarsely crystalline character which is supposed to be typical of the filling of open spaces. It should be noted, however, that the quartz grains do not exceed a millimeter or two in width, and in no case do they form the very coarse comb quartz seen in many fissure veins. The nearest approach to this structure is seen where quartz crystals partially filled the drusy cavities resulting from the dissolution of limestone fragments.

Attention has already been called to a replacement that is more in the nature of pseudomorphism than that which has just been mentioned. This phenomenon has been described in discussing the character of the ores, and it has been shown that the shattered limestone has been penetrated by solutions which deposited films of silica; that subsequently the limestone has been dissolved away, leaving the silica as the division walls of a very loose cellular material; and, lastly, that secondary waters have deposited silica upon these thin walls until in many cases the cavities have been completely filled by some of the coarse quartz, showing comb structure, while in other cases the open spaces have been but partly filled and show drusy centers. The galena ores of the foot-wall bodies show even better evidence of replacement. The hand specimen, of which a photograph one-half natural size is reproduced in Pl. LIV, shows a limestone sheeted by fractures parallel to the bedding and the resulting slabs broken into rectangular blocks. These blocks are now firmly cemented together by galena ore carrying zinc blende and a little pyrite. The accompanying plate presents a photograph of both sides of the specimen, showing how the dolomite blocks seen on one side are almost entirely replaced on the other. The thin sections of the galena ores show particularly conclusive examples of the replacement of the dolomite. The dolomite rhombs are irregularly penetrated along cleavage planes and to a lesser extent by irregular, sack-shaped cavities, often into their faces, by galena and the accompanying silica. The silica is in part crystalline, but in large part of the cryptocrystalline variety so characteristic of metasomatism. Finally, what might be called negative evidence in favor of replacement also exists in the absence of open caverns, partially filled open spaces, the total absence of crustification, and the fact that the hanging-wall slate was attacked but slightly by the mineralizing solutions.

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[1] Gold-quartz veins of Grass Valley, California, by Waldemar Lindgren: Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, p. 391.

SOURCE OF THE METALLIC CONTENTS OF THE ORES.

The metallic contents of the Elkhorn deposits are believed to have come from the igneous rocks lying beneath the limestones. That the ores are the result of uprising siliceous waters is established by the facts already set forth. That these waters were hot is extremely probable, since there is abundant geological evidence that the successive igneous intrusions heated the entire district and that fumarolic activity prevailed, as is shown by the occurrence of axinite, tourmalines, and other minerals in the rocks.

As already stated, the ore deposit has been formed since the gabbro intrusion and the accompanying metamorphism of the sediments. The gabbro is rich in augite, mica, and iron ore, and often contains pyrite in considerable abundance. Some of this pyrite seems unquestionably to be of primary origin. The occurrence of metallic sulphides in such basic rocks is, however, well established by observations elsewhere, notably those of Vogt in Sweden, Adams in Canada, and Kemp in the United States. No definite evidence has been obtained proving that the Elkhorn rocks are especially rich in silver and lead, yet the presence of metallic sulphides and the geological facts all point to the gabbro as the source of the metallic contents. Ore deposition probably took place after the intrusion of the granite batholith. The profound changes resulting from the presence of this enormous mass of rock, which obliterated the former rocks over an immense area and produced a great heating about the borders of the intrusion, all indicate conditions favoring a shattering of the gabbro and a leaching of deep-seated portions of the mass by uprising waters following the granite intrusion. It is evident also that the pneumatolitic action accompanying the cooling down of so large a mass must have greatly stimulated the circulation of hot waters and vapors; although no definite evidence of former hot-spring action is now recognizable by any surface deposits, the observed facts all point to the former presence of hot waters. It is true that there is a certain amount of evidence proving a differentiation of the granite about its borders, and that these basic differentiation products may have been leached by the circulating hot water, but it seems reasonable to suppose that the gabbro, a more basic rock, afforded some favorable physical conditions for the leaching and extraction of its precious-metal content. The gabbro now exposed in the district is very fresh, or shows only surface alteration, and therefore it could not have been leached, as such action would leave definite signs of solfataric action. The leaching must have been in more deeply buried portions, and the uprising mineralized waters, following lines of least resistance, were concentrated by the impervious shales in the course now marked by ore shoots. The pinching out of the deposit in depth and its impoverishment in values in the deeper workings are at first sight more favorable to the theory of precipitation from descending solutions than of precipitation out of ascending waters. As already shown, however, the deposition took place on the under side of a pitching anticlinal fold, and this is positive evidence that the waters were ascending currents. Moreover, the workings show that the ore channels do not disappear in depth, as quartz is seen in the 2,300-foot level, the bottom level of the mine, where it still carries metallic sulphides. Besides, the verticals of the Black Hills region—of whose existence and character we now have very definite data—are examples of extremely small and often barren fissures, sometimes mere cracks in the rock, which serve as feeding channels for the siliceous ores formed by replacement along the bedding planes between limestones and less soluble shales or quartzites.

It should be remembered, also, that in solutions slightly varying conditions may change or even reverse the chemical action, solution and deposition being really relative terms. Varying temperature and pressure are the factors which disturb chemical equilibrium. A solution may dissolve metallic sulphide under the pressure and temperature prevailing during the cooling down of the granite batholith and carry them upward without precipitation. In such cases physical conditions did not favor precipitation, and the sulphides were deposited only when relief of pressure and cooling have permitted their precipitation. One can conceive that under stable conditions uprising hot waters flowing in trunk channels would show a lower zone in which the waters would be capable of taking the metals into solution; above this another zone where the waters would hold metallic sulphides in solution but would not precipitate them; and a third zone, above the last, in which precipitation would occur. Near the surface the least soluble metallic sulphides would have all been precipitated and the hot waters issuing as springs would deposit only silica and the more readily soluble salts. It must, of course, be understood that in this theoretical arrangement there would be a gradation from one zone into another, and that the metals should show a fairly orderly vertical distribution. This is in fact what we find in the Elkhorn deposit, where the ores show galena underlain by zinc and passing into pyritiferous ores in depth. The occurrence of this deposit on the border of the granite batholith is analogous to that of many of the great ore deposits of Montana. The Granite Mountain mine, the Drumlummon, the mines at Winston, and the Whitlatch Union lode, near Helena, are all familiar examples of rich ore deposits formed in veins traversing similar contact rocks.

SECONDARY SULPHIDE ENRICHMENT.

The extensive oxidation of ore bodies, converting them in the upper part of the mine into carbonates and oxides, has been accomplished by a partial leaching out of the silver contents from large masses of ore. This oxidizing action with lixiviation is less prominent in depth, and, in the lower ore bodies, has gone no further than to form a cap of oxide ore above the ore body. There is, however, abundant evidence that oxidizing waters have penetrated to the greatest depth yet reached in the mine, 2,300 feet on the dip. The ores from this level show partially altered galena with oxide coatings, and tetrahedrite partly converted into sooty black sulphides; moreover, open water courses are found in the dolomite, and the quartzose ore, taken from the freshly opened face of the 2,300 quartz body, showed the sulphide minerals partially oxidized, while the quartz was porous and held little rust-stained cavities.

It has been shown[1] that where ore bodies are leached by oxidizing waters the descending solutions may precipitate their metallic contents by reaction with lean primary sulphide ores. This reaction is prominent, however, only where the original sulphides contain much pyrite or other iron sulphides. The absence of such ores in the shoots worked in the Elkhorn mine would explain the absence from the ore bodies thus far worked, but it does not explain why they do not occur in the pyritic ores found in the lower levels. There is, it is true, some evidence indicating the secondary nature of tetrahedrite and of local bunches of secondary sulphides, but it appears probable that the failure to form large bodies of such secondary ore is due to the massive and unbroken condition of the ore bodies which were not freely penetrated by descending waters. Moreover, the mine waters are not acid and do not contain ferric sulphate, so that it is evident that favorable conditions for secondary enrichment did not generally exist. The impoverishment of the ores in depth may perhaps be due to a slight enrichment of the upper levels. While it is not believed that galena exercises any amount of action upon descending solutions, it must be admitted that some of the very high-grade galena found in the mine, that was partly altered and showed sooty films along the cleavage plates, may have been rich in silver sulphides. However, the impoverishment of lead-silver deposits in depth, and their passage into low-grade zincky ores, is a common phenomenon in the mines of the Rocky Mountain region. It has been especially noted by Rickard.

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[1] Enrichment of mineral veins by late metallic sulphides, by W. H. Weed: Bull. Geol., Soc. Am., Vol. XI, 1900, pp. 179-276. Enrichment of gold and silver veins, by W. H. Weed: Trans. Am. Inst. Min. Eng., Vol. XXX, 1900, pp. 424-448.

AGE OF THE ORE DEPOSIT.

The geological evidence which has been presented in the foregoing pages proves that the rock metamorphism of the strata containing the ore deposit is mainly the result of the intrusion of the granite batholith, and it follows from this that the ore deposit is younger and has not suffered metamorphism. It is believed that the deposit was formed shortly after and is a sequel to the granitic intrusion, and hence is of late Eocene or early Miocene age. The rhyolite intrusions and outbursts which took place at neighboring localities in middle and late Miocene time were, it is true, followed by ore deposition at some places, but there is reason to believe that the Elkhorn deposits were not the result of this period of dynamic activity, but that, like those of Butte, they preceded the rhyolitic intrusions.

CHAPTER IX.

NOTES ON OTHER MINES OF THE DISTRICT.

Although the Elkhorn mine is the only one in the district which has yielded any large amount of mineral wealth, there are a number of other fractures which are interesting scientifically and which have been more or less developed in the last twenty years. None of them have as yet been developed into paying mines. This is in large measure due to the fact that the ore which has thus far been produced has been of extremely low-grade character. So far as known, none of these mines show the favorable physical conditions which prevail in the Elkhorn. The following brief notes have been made on the deposits:

The C. and D. mine is situated about a mile north of the Elkhorn. The ore body lies in the marbleized Madison limestones, near the granite (quartz-monzonite) contact. The mine has a shaft 250 feet deep, with several levels, and a tunnel which crosscuts through the limestone to the granite contact. The mine was not examined in detail, as it was not accessible. The deposit is not a true fissure vein, but according to Mr. Kelley contains deposits of low-grade pyritic ore, with occasional bunches of galena in limestone, the former ore being too low grade to pay expenses under ordinary circumstances. The mine has been leased at various times to different parties, and in 1898, by reason of an extremely favorable contract with the East Helena smelter, which desired its oxidized iron ores, it was worked for a while. A considerable number of car loads of ore were shipped, although the ore ran only from $1.50 to $2 per ton in gold and was low in silver. Several car loads of galena have been shipped from the mine, coming from chambers in the limestone. The granite contact shows a pyrite lead, but this ore also was too low grade to work. The product of this mine has already been given in the first chapter of this report.

The Keene mine, which lies about 1,000 feet north of the Elkhorn, was worked in a desultory way for about twenty years. It is said to be developed by a 150-foot shaft and by a tunnel running several hundred feet into the hillside and having drifts on the vein. The ore is an oxidized ferruginous material, said to carry good values in gold. It occurs along the bedding plane between an underlying limestone (the Keene limestone) and an overlying argillaceous bed. While the observations made were not detailed enough to show the actual structural relations, it is believed that this deposit is formed along an impervious stratum and that the horizon may be expected to yield workable ore bodies where the contact forms a pitching anticlinal fold, permitting saddle deposits. The mine stopes show some evidence of slipping or accommodation along the contact plane, but as the shaft had caved in at the time the mine was visited and the workings were not safe no detailed study was made.

The Union mine is situated at the head of Alpreston Gulch, in the limestones near the granite contact. The property has yielded several railroad car loads of silver-lead ore, but the ore bodies are not continuous and the average value of the ore is said to be too low to warrant working. The property was worked in the early eighties, and the development in 1884 consisted of an 80-foot shaft and a 240-foot tunnel. The ore extracted at that time is reported to have carried 80 to 350 ounces of silver per ton.[1]

The Dolcoath mine differs from those previously mentioned, and indeed, so far as known, from all other property known in the State. The ore shows free gold in the upper weathered parts of the body, and the unaltered portion consists of glittering metallic spots of bismuth sulphide and telluride (bismuthinite and tetradymite). The ore-bearing stratum is from 15 to 18 inches thick and dips northeast at an angle of 45° to 50°, the strike being N. 5° W. The mine has been opened by an incline shaft 170 feet deep, with a level at 100 feet, and another at the bottom of the shaft driven in both directions. The ore-bearing stratum is clearly an impure limestone altered by contact metamorphism and now consisting of garnet (grossularite) with lesser amounts of diopside and spots of calcite. The rock is coarsely granular, the garnet being the coarser mineral, and the diopside filling interspaces; the calcite exists in strings, veinlets, and bunches, which are evidently the filling of drusy cavities also showing garnet crystals and of fractures in the garnet itself. The calcite masses are, however, often similarly oriented and appear to be singular individuals which seems opposed to their deposition in open spaces. The ore minerals have been examined in the chemical laboratory of the Survey by Dr. H. N. Stokes, who reports that they consist of bismuth sulphide (Bi_2S_3) 86.7 per cent, bismuth telluride (Bi_2Te_3) 13.3 per cent. Dr. Stokes says that much of the sulphide was found to be free from the telluride. Whether the latter is tetradymite with or without sulphide could not be positively determined, nor could it be determined which mineral carries the gold. Bismuth sulphide is the mineral bismuthinite, and it has altered in the upper portion of the ore deposit to the carbonate bismutosphærite, which occurs as a yellow, powdery material, and has dark-brown dendritic markings. The tetradymite contains some copper, and in this respect accords with the analysis made by Genth, which is recorded in Dana's Mineralogy. In the altered material this copper has stained the rock with malachite. The bismuth minerals occur scattered through the ore in minute grains disseminated throughout the garnet, in larger grains in the diopside, and as particles varying up to a quarter of an inch across, which appear frequently to be associated with the calcite.

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[1] Report of Director of Mint on Production of Gold and Silver, Washington, 1885, p. 304.

A study of the partially altered ore leaves no doubt that the gold occurs as a constituent of the bismuth minerals and that it has been freed and left as native gold by their oxidation. The gold is somewhat dull and rusty and has the habit often observed by the writer when it is undoubtedly derived by oxidation from tellurides. The ore stratum is overlain by impure marble and underlain by a similar lime-silicate rock. A short crosscut driven into the foot wall showed the presence of an intrusive sheet of gabbro-diorite at a distance of about 18 feet from the ore body. The ore in this stratum is probably the result of pneumatolitic action, due either to circulating vapors or, more probably, to circulating hot waters rising upward through it. As suggested by Dr. Barrell, the metamorphism of an impure limestone would produce a somewhat porous rock, since the minerals produced by contact metamorphism occupy less volume than the original rock. The action is somewhat analogous to that of the baking of brick, in each case the action being due to heat. An examination of thin sections of the wall rock has been made by Dr. Barrell and shows that they are purer limestones and that the resultant product is far less pervious to water than the ore-bearing stratum. It is believed, therefore, that as the rocks are tilted and slightly folded the pressure was not sufficient to close up the pores in the rock, and that, being confined by the relatively impervious stratum above and below, the uprising waters followed this horizon and deposited their metal contents, together with calcite, in the interstices of the rock.

It has been impossible to obtain any data concerning the various other properties of this district, as all the shafts are filled with water or the tunnels are inaccessible. The report of the Director of the Mint upon the production of precious metals for 1884 contains a short account of a number of mines upon which considerable development work had at that time been done. Thirteen properties are mentioned besides the Elkhorn mine. Three of these—the Union, C. and D., and Keene mines—have already been mentioned; the others include a number of ore bodies situated close to the Elkhorn mine, none of which have, so far as it has been possible to ascertain, been worked within the last ten years. The notes mentioned give a little information concerning the geological character of the ore deposit.

The Relief mine, located a quarter of a mile northeast of the Elkhorn, is said to have shown at a depth of 20 feet a 12-foot vein of silver ore giving assays of 50 to 100 ounces per ton.

The Paymaster, located 400 yards north of the Elkhorn mill, showed a 4-foot face of ore along a slate-dolomite contact.

The Homestake and the Dunstone.—The Homestake, three-fourths of a mile northwest of the Elkhorn, and the Dunstone, 600 yards northwest of the Elkhorn, show ore bodies in dolomite.

The Monte Cristo, the Luxenburg, and the Mountain View.—The Monte Cristo, 1,000 yards west of the Elkhorn, contains a 10-foot vein of copper ore lying in slate and granite. The Luxenburg, one-half mile south of the Elkhorn mine, showed at a depth of 35 feet a 6-foot vein of ore carrying copper and lead, as well as the precious metals, the country rock being granite. To the north of the Elkhorn mill, the Mountain View property, situated 1½ miles up the gulch, is said to have shown a 3½-foot vein of silver-lead ore in slate and syenite.[1]

IRON MINES OF ELKHORN PEAK.

On the north shoulder of Elkhorn Peak, about 700 feet below the summit, there are two deposits of iron ore that are exposed by open cuts and underground drifts, and from which considerable ore has been shipped at various times in the last ten years. The property is reached by a steep but fairly good wagon road, leading from Elkhorn up Alpreston Gulch and over a spur of Elkhorn Peak, a distance of about 4 miles. The ore bodies occur beneath the great marble inclusions in the andesites of Elkhorn Pèak, and form the white cliffs so prominent in all views of this mountain. These inclusions are underlain in places by thin seams or lenses of magnetite and garnet. In general these seams are too thin to be of economic value, but on the northwest side of the peak they are thick enough to constitute workable ore deposits. The ore is always found along the bottom of the marble mass, and is undoubtedly a replacement of it. It rests on andesite, which is badly decomposed and rich in iron wherever it was seen exposed. The marble above the ore is not over 15 feet thick. The ore itself is a massive fine-grained magnetite, showing rare grains of chalcopyrite and an admixture of garnet. Green stains of copper carbonate occur on the weathered crust. The mass of garnet present varies considerably, and it is possible to obtain very high-grade ore by sorting the material. This ore is said to carry small values in gold, but no assays were made to prove the accuracy of this report. The only use for iron ores in Montana as yet has been in the smelting establishments, as a flux for siliceous ores. The Elkhorn material has all gone to the East Helena smelter. The property is reported to have been bonded in July, 1900, to the Helena and Livingstone Smelting and Reduction Company for $15,000, as a source of flux for the smelter just mentioned. Deposits similar to those at Elkhorn have been noted by the writer about igneous intrusions in other parts of the State, notably in the Little Belt Mountains. They are commonly regarded as the result of the alteration of contact deposits of pyrite. Cross and Emmons have noted similar deposits at numerous places in Colorado, and have ascribed them to the decomposition of pyrite. It has been suggested that the Elkhorn deposits might be altered limonite replacements formed by waters flowing down the andesite surface underneath the marble. Of this, however, there is no proof, whereas there is definite evidence to show that similar deposits elsewhere have originated from the alteration of pyrite masses.

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[1] Report of the Director of the Mint for 1884, pp. 304-305.

The Jacquemin mines are situated in the gulch of Iron Creek a mile northwest of the town of Elkhorn. They were worked energetically during the summer and fall of 1898, but in 1899 they were closed down, and the bad air of the tunnel made an examination of the ore body impossible. The mines were worked for a while to supply a temporary demand for iron ores for the East Helena smelter. The opening up of the War Eagle mine, near Helena, furnished a nearer and cheaper source of supply, and this property was closed down. The workings comprise a tunnel driven for several hundred feet through granite to a contact of altered Cambrian (Starmount limestone). The ore is oxidized and appears to be a mixture of hematite and limonite, and is probably an alteration of a contact deposit of pyrite.

The Elkhorn Queen is situated east of Queen Ridge and just outside the limits of the map. This property, which was shut down at the time of the writer's visit, has been visited by Mr. Kelley, who states that it shows a pipe of porphyry in limestone, with a shell of ore about the contact. During May and June, 1900, more than 1,000 tons of ore have been shipped from the Elkhorn Queen to the Peck concentrator at East Helena. The vein is said to be 24 feet wide, and while values are low the immense quantity makes it easy to mine, and although small profit per ton can be realized the large tonnage is expected to make it pay large dividends.

FUTURE OF THE DISTRICT.

The closing down of the Elkhorn mine and the dismantling of the surface works is by many regarded as the end of the mining industry of the district. From the daily press comes recent information that the Elkhorn Company's property has been sold and will be reopened. If this be true it is to be hoped that some prospecting will be done to see if the main slate-dolomite bedding plane (or contact) does not form another saddle to the north. If the extension of the 300-foot level showed such a bend, as a result of another pitching arch of the strata, another ore body can be confidently looked for. Moreover, the only hanging-wall crosscuts have been driven in the intervals between the arches carrying the ore. The 1,050 hanging-wall crosscut passed through, at 60 feet from the level, a blue limestone whose contact was marked by ore. If ore was found here—in an unfavorable locality—there is reason to believe that ore bodies will be found in the saddle above the big ore shoots. In the well-known "saddle reefs" of Australia, which are deposits formed in pitching anticlines, ore bodies are found in successive saddles one above another. The vertical sections commonly given in text-books and the illustrations in descriptive reports do not disclose the close analogy to Elkhorn which the descriptive text shows to exist. It is certain that at Elkhorn there were at least three impervious strata—the Elkhorn shale, the contact cut at 60 feet above it, and the shale belt of the Keene mine. These three contacts are all marked by a little ore, and the contacts should be carefully searched where pitching arches would afford favorable conditions for ore shoots.

MICROSCOPICAL PETROGRAPHY OF THE ELKHORN MINING DISTRICT, JEFFERSON COUNTY, MONTANA.

By JOSEPH BARRELL.

INTRODUCTION.

In this report there will be presented an account of the petrographical features of the various rock types of the Elkhorn mining district. The work is the result of a careful study of the rocks and their sections in the laboratory of the Sheffield Scientific School of Yale College, under the supervision of Prof. L. V. Pirsson, this paper on the petrography forming a chapter in a thesis entitled The Geology of the Elkhorn Mining District, presented for the degree of doctor of philosophy in May, 1900. This report treats first of the unaltered igneous rocks, and separately of the altered sedimentary rocks, the metamorphism of which was produced by the heat and vapors of the igneous intrusions.

UNALTERED IGNEOUS ROCKS.

Under this heading an account will be given of the igneous rocks of the district that are unaltered by contact or later weathering. As they form part of the series of rocks formed from the earlier Tertiary igneous activity of this part of Montana, the results of the study apply to a widespread area as well as to the Elkhorn district. A general account of these has been given by Mr. Weed in the paper preceding this, and it is to be noted that, while no unusual types are found, considering the limited area a great many varieties are represented, belonging to consecutive epochs of eruptive activity. Referred with probability to the oldest period are a number of dikes emanating from a syenitic magma but showing extreme differentiation from acid to basic types. These have been observed in the Elkhorn mine and also in the southern part of the district within a mass of Starmount lime-silicate rocks isolated from the other sedimentaries by later eruptives. Following these at an unknown interval came a period of great eruptions from dioritic and gabbroic magmas, forming the Black Butte stock of gabbro, the laccolithic intrusion of diorite-porphyry, numerous dioritic and gabbroic dikes, the intrusive and extrusive areas of andesite found in the northern and southern parts of the district, and perhaps the Cemetery Ridge stock, though the relations of the latter to the other eruptives are not well shown. After this there was an irregular and branching intrusion of quartz-diorite-porphyry across the southern part of the district, and finally came the breaking of the quartz-monzonite of the batholith across the western border. The intrusion of aplite dikes through the quartz-monzonite and the adjacent sedimentaries marks the close within this area of the eruptive actions.

The plan of this report is to describe the microscopical features of these rocks, pointing out any peculiarities, to give the chemical and mineralogical compositions, and to indicate, where possible, what relations may exist among them. Chemical analyses[1] of the principal rock types are given, but in the descriptions these are supplemented throughout by estimated mineral or chemical compositions as determined by the microscope.

In those classes of rocks where the minerals are clearly separated from one another an estimate of the chemical composition sufficiently accurate for many purposes may be obtained by the use of the microscope. The percentages of the several minerals and their composition are first determined. In those minerals, such as the pyroxenes or hornblendes, where certain elements may replace each other in unknown quantities, the general character of the rock will enable one to decide approximately what composition to assign to them, but as they usually form but a small part of the rock the final error resulting from this source is correspondingly reduced.

The composition of the feldspars is usually susceptible of accurate determination. Where possible the method of Michel Lévy[2] is used, depending upon the extinction angles observed in crystals twinned according to both the albite and Carlsbad laws and cut nearly perpendicular to the clinopinacoid. Where the section is not favorable for the application of this method a variety of other methods may be employed, such as the relation of the vibration direction to the cleavages shown in clinopinacoidal sections and the positions of the optic axes.

For estimating the percentage of the constituent minerals of the section any one of a number of methods may be used, that which is chosen depending upon the degree of precision desired. In this work the method employed is as follows:

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[1] These analyses were made for me by Dr. H. N. Stokes in the laboratory of the United States Geological Survey. The careful nature of the work of Dr. Stokes is well known, and it is a pleasure for me to call attention to the close correspondence between the mineralogical and chemical compositions of the rock types described herein.—W. H. WEED.

[2] Étude sur la détermination des feldspaths, 1894. Same, second fascicle, 1896. On the determination of plagioclase feldspars in rock sections, by George F. Becker: Am. Jour. Sci., 4th series, Vol. V, May, 1898, p. 349.

The field of view of the microscope is divided into quadrants by the cross hairs, and these are mentally divided into sectors which are thirds, fifths, or smaller fractions. By taking such a power of objective that the component to be estimated is represented in the field of view by a fair number of crystals, the latter can be mentally collected together and packed into one quadrant, and the fraction which it fills estimated.

If not enough of the section can be seen in one field of view to give a representative idea of it, a number of gages must be taken, this being done while the minerals are under study, so that no time is consumed, and it will be found that with a little practice a fair degree of precision may be reached. As the one thin section under study is not presumed to be an accurate average of the rock mass, it is not often that a more exact method of estimation will be called for.

In the case of holocrystalline rocks, where the writer has been enabled to check this method of estimating the mineral and chemical composition by comparison with laboratory analyses, it is found that the error in any one element should be less than 1 per cent and is often less than one-half per cent.

BLACK BUTTE STOCK AND ASSOCIATED DIKES.

This stock, more fully described elsewhere, is an intrusion half a mile in diameter, with very irregular boundaries, situated three-fourths of a mile northwest of the town of Elkhorn. It has broken through the Lower Paleozoic limestones, and on the west is itself sheared off by the later intrusion of the batholith. On the other three sides are many small outlying stocks and stock-like dikes, consisting of rocks of similar composition and connected with it in origin. The cliffs and loose bowlders present a coarse-grained, weathered surface of a dull-grayish black. On fresh fractures labradorite shows as a deep-gray groundwork, biotite in intense black clusters, and augite and hornblende as dull black crystals, usually with poorly defined boundaries.

In the coarser-grained varieties these distinctions can be readily made out, but in the denser forms only a fine-grained, uniformly dark surface is presented to the eye.

The coarseness of texture shows no very marked relation to the nearness to the walls. These appear to have been thoroughly heated before crystallization took place, and other causes have been chiefly operative in determining the granularity and general appearance of the rock.

The material of this intrusion is typically a gabbro, but shows considerable variation in composition, leaning in some places toward the anorthosites, in others toward the pyroxenites, and passing in the outlying dikes into diorites. In the following table the composition of the representative rock is given, and is compared with that of the gabbros of the southwestern Adirondack region, to which this rock bears a strong resemblance.

Analyses of gabbros from Montana and New York.

Constituent.	A.	B.
SiO_2	47.44	46.85
Al_2O_3	18.21	18.00
Fe_2O_3	5.37	6.16
FeO	6.05	8.76
MgO	5.53	8.43
CaO	9.98	10.17
Na_2O	2.58	2.19
K_2O	1.17	.09
H_2O at 110° C	.13	.30
H_2O above 110° C	1.08	
TiO_2	1.38	
CO_2	None.	
P_2O_5	.68	
S	[a].03	
Cr_2O_3	None.	
NiO	None.	
MnO	.06	
BaO	.08	
SrO	.08	
Li_2O	Trace.	
	99.85	100.95

[a] Undetermined whether sulphide or sulphate.

A. Normal gabbro from west side of Black Butte, not far from the limestone contact, Elkhorn, Mont. Analysis by H. N. Stokes.

B. Hypersthene-gabbro from the southwestern Adirondacks, New York. C. H. Smyth, jr., American Journal of Science, July, 1894.

The rock is seen to be a normal gabbro, but differs somewhat from any from Montana yet described by the United States Geological Survey in having a rather high percentage of alumina compared to the amount of silica. This expresses itself in the mineral composition by an abundance of labradorite.

To show the variations in composition within the stock and also in the adjacent dikes the following table is given. The percentages are estimated by the microscope and are given by volume. The magnetite being the mineral of greatest specific gravity, the most noticeable change in converting these into percentages by weight would be a slight raising of the amount of magnetite and a lowering of the labradorite. For purposes of comparison the composition by volume, being that directly obtained by the microscope, will suffice equally well.

Mineral composition of igneous rocks from Black Butte stock and associated dikes.

Mineral.	1.	2.	3.	4.	5.
Labradorite	37	63	67	70	33
Augite	45	20	8	1	8
Hornblende	8	2	15	19	....
Biotite	6	10	6	8	1
Magnetite	4	4	1	.5	4
Quartz	....	1	3	2	....
Apatite	.5	....	....	....	....
Zircon	.1	.1	....	....	....
Hypersthene	....	....	....	....	4
Groundmass	....	....	....	....	50

1. Gabbro from near northern side of main stock (144).
2. Gabbro, west side of Black Butte, near limestone contact. See analysis on page 514, by N. H. Stokes (155–156).
3. Gabbro-diorite from small intrusion half mile north of Black Butte (64).
4. Diorite. Inclusion in later eruptive 4,000 feet south of Black Butte (17).
5. Andesite-porphyry, from same inclusion as No. 4; a different portion of same mass (90).

NOTE.—The numbers in parentheses after all tables refer to field numbers given to localities and to specimens taken from them.

The similarity of Nos. 2, 3, and 4 is to be noted, No. 2 coming from the stock, while 3 and 4 are from outlying intrusions 6,000 feet apart. The latter two closely resemble each other in microscopic appearance as well as in composition, and all are blackish-gray holocrystalline rocks, noted under the microscope for their large percentage of labradorite, which runs in composition from $Ab_1 An_2$ to $Ab_3 An_4$, the entire series possessing also a notable amount of biotite.

No. 2 compared to No. 1 shows the variation in composition within the same stock, and Nos. 4 and 5 exhibit a similar contrast for an outlying fragment of the same magma, originally an intrusion, but now held as an inclusion within the quartz-diorite-porphyry, which occupies a considerable area south of Black Butte.

In regard to the original relations of Nos. 4 and 5 to the strata which once surrounded them, not much can be said, since they are now parts of an inclusion within a later eruptive. Their difference in mineral composition between themselves must be noted, however, as indicating the rapid changes which may take place within the same intrusion. The association of minerals is seen on comparing the several sections. Free quartz exists in those with much biotite and hornblende, even in the presence of those minerals characteristic of the more basic rocks, but avoids those parts of the stock in which the magnetite and augite are high and the biotite and hornblende low. It is to be noted that where the quartz is present the labradorite feldspars are zonally built in the outer parts, indicating a greater content of soda and silica and a transition toward the albite molecule, a feature quite absent in the most basic gabbros.

The greater percentage of labradorite in certain sections of the stock, and its matted manner of occurrence, when taken in connection with the fact that in the gabbros it is the first mineral to crystallize, suggest the explanation that the cause of the segregation has been the cooling of the walls. The moving and settling of the magma within the stock while undergoing crystallization would afford opportunity for the labradorite to crystallize against the contacts, exhibiting a parallelism in orientation, while the other constituents were still in the fluid condition, resulting in a concentration of the labradorite at the sides and of the iron ores and augite toward the center. If this is the true interpretation it is worthy of note, since in the more acid magmas it is the iron ores and ferromagnesian minerals which are the first to crystallize and which by that means are often concentrated near the borders of an intrusion.

The thatched or matted manner in which the labradorite crystals lie upon one another is not strictly confined to the margin, and the same process may have been continuous for some distance inward, provided there was a slow movement of material within the throat as the crystallization proceeded.

ROCKS OF THE CEMETERY RIDGE STOCK.

This area of eruptive rock, a half mile in width by three-fourths of a mile in length, lies immediately east of the town of Elkhorn. Like the one previously studied, it has broken through the Paleozoic limestones and possesses a very irregular margin. At the surface it is entirely isolated from contact with all of the other eruptives of the district, and this, in addition to its highly altered condition and the absence of fresh material for study, renders its relationships somewhat doubtful. The rock where freshest is seen to possess a holocrystalline texture and the appearance of a diorite. In its present condition it shows the influence of both extensive subaerial and subterranean alteration. The surface weathering has produced rust-colored bowlders and a general decay for considerable depth, but the more extensive form of alteration has resulted in the production of serpentine and probably other hydrous ferromagnesian silicates also, leaving in places no trace of the original holocrystalline texture. These alteration products are well exposed in the railroad cut immediately south of the Elkhorn station, showing as white to yellow, many-jointed surfaces. Occasional nuclei of the original igneous rock point conclusively to the origin of the hydrous ferromagnesian silicates, and that the alteration process is not a surface one is shown by the occurrence of the same materials in the Elkhorn mine at depths of 800 feet below the surface on a drift driven southward to prospect this locality. As to the character of the unaltered rock, only the following notes are available, the mineral compositions being given by volume and estimated by the use of the microscope.

Mineral composition of rocks of Cemetery Ridge stock.

Mineral.	A.	B.	C.	D.
Orthoclase	2	80	33	
Microcline	1			
Labradorite (Ab_3 An_4)	43			
Labradorite (Ab An)			44	
Total feldspar	46	80		75
Quartz			15	5
Biotite	1	8		
Hornblende			5	15
Pyroxene	50	0.8		
Pyrite	3	2	2	2
Titanite		2	1	
Garnet		6		
Decomposition products		1		3
	100	99.8	100	100

A. Specimen from half a mile west of the town of Elkhorn, near the northeastern margin of the stock (12).

B. Specimen from a dike cutting the limestone on the south drift of the 1,050-foot level of the Elkhorn mine, at a point under the northwestern margin of the stock (187).

C. Quartz-monzonite from the Elkhorn mine. Collected in 1896 by Mr. W. S. Kelley.

D. Specimen from a dike conformable to the limestones exposed on the railroad 2,000 feet west of the stock (8).

The rock from the margin of the stock, represented by A, is dense and dark in appearance, and is seen to be a gabbro. The fragments of metamorphosed limestone found within the stock at the surface, and still maintaining their proper orientation, indicate that the present surface is near the former roof. In this locality, then, basic segregations would be expected to occur, and deeper down the stock may be more siliceous.

The dike found in the mine, and whose composition is given under B, is so near to the main stock that the probability of its relationship to the latter is strong, though by no means proved. The rock is fresh and granular in appearance, of a light-gray color, and with many sparkling points of pyrite. It is essentially an orthoclase rock, and shows affinities with the syenite dikes found in the extreme southern part of the district. Its unlikeness to A is another indication that, though in proximity to the Cemetery Ridge stock, it may not be related to it. Its further discussion is reserved for the section on syenites.

The rock given under C has the composition of an acid diorite or quartz-monzonite, differing conspicuously from B in possessing much plagioclase and quartz. It was collected from the same drift as B, but owing to its unlikeness can not be regarded as belonging to the same intrusion as the latter.

The rock whose mineral composition is given under D is a micro-diorite occurring in a dike 50 feet in thickness, comformably bedded with the limestones, but exposed for only a short distance. It is quoted because it is the large intrusive nearest to the stock, but does not have any evident relation to it.

In default of further material from the stock itself, its general character and affinities remain in doubt, the probability being that it is a diorite, passing in places into a gabbro, perhaps in other places into a quartz-monzonite.

SYENITE DIKES.

There are a number of thin dikes and sheets varying greatly among themselves but possessing the common characteristic of being without quartz and containing an abundance of alkaline feldspar. Owing to their thinness, and also to the fact that they are usually bedded with the strata, they are very liable to escape observation except where exposed by fresh cuttings. The only exposures noted have been in the Elkhorn mine workings and in a railroad cut in the southern part of the district. For these reasons they may be more abundant within the district than is supposed, especially as, where occurring near other eruptives, they are sometimes not readily discriminated in the field.

Those found in the extreme southern part of the district are in a mass of metamorphosed Starmount argillaceous limestones, 400 feet in thickness, entirely isolated from the neighboring sedimentaries, being underlain by intrusions of quartz-diorite-porphyry and andesite and capped by the diorite-porphyry laccolith. Within these light-colored, calcareous, metamorphic rocks they occur as sheets and dikes from a fraction of an inch to 18 inches in width. They range from white, coarsely granular rocks, consisting almost entirely of microcline and hardly to be distinguished from the inclosing strata, to shonkinites, dark in color and coarsely granular, in which half of the rock consists of augite and biotite.

Before describing them in detail, a synopsis will be given of their mineral composition, by volume, as estimated by the microscope.

Mineral composition of the Elkhorn syenites.

Mineral.	A.	B.	C.	D.
Orthoclase	80			49
Microcline		88	73	
Labradorite			4	
Anorthite				5
Biotite	8			25
Augite	.8	5	20	20
Ægirine				1
Apatite		.2	.1	
Titanite	2	1	3	
Garnet	6	4		
Pyrite	2			
Secondary products	1	2		
	99.8	100.2	100.1	100

A. Garnetiferous syenite from the 1050 south drift of the Elkhorn mine, a dike cutting the foot-wall marbles (187).

B. Bostonite. A dike 5 inches in width, perpendicular to the strata, in the isolated mass of Starmount metamorphosed limestones (170).

C. Augite-syenite. A sheet 18 inches in width in the isolated mass of Starmount metamorphosed limestones. Dikes B and C intersect, but the point of intersection is concealed, and therefore their relations at that point are undeterminable (171).

D. Shonkinite. A sheet of irregular width and occurrence, in the isolated mass of Starmount metamorphosed limestones, 75 feet south of C (174).

The orthoclase or microcline in all of these specimens contains considerable soda, as is indicated by the mottled extinction when rotated between crossed nicols. Carlsbad twinning is common and the microcline shows fine watered effects. The alkaline feldspars were the last minerals to crystallize and hold all the others enmeshed. Where they form the bulk of the rock the individual crystals are from 2 to 3 mm. in length and one-half to 1 mm. in thickness, but in certain places they become much coarser, sometimes giving cleavage faces an inch in length. The crystals show a tabular development along the plane 010, the clinopinacoid. Although in the types rich in alkaline feldspars the latter thus assume something of their crystalline form, the final junction line, with adjacent crystals of the same species, is very irregular, as is to be expected, since these have been the final products of crystallization and have necessarily grown until they have met each other. Thus the rock shows the panidiomorphic structure of Rosenbüsch, each crystal of orthoclase assuming somewhat its proper crystallographic form, but exhibiting none of the sugar-granular aplitic structure.

In the augite-syenite and shonkinite a certain amount of plagioclase occurs in scattered and sharply idiomorphic crystals from one-half to 1 mm. in length.

The ferromagnesian components are either mica or augite, or both.

The augite occurs in idiomorphic prisms from one-fifth to 2 mm. in length and shows strong pleochroism, the color along the several axes being bright green, greenish blue, and light yellow. The crystals are scattered throughout the section, though more abundant in some parts than in others. The very striking mottling of C of the above table, the augite-syenite, as seen in the hand specimen, of which a photograph is given (Pl. LXII, *A*), is due to the uneven distribution of the almost microscopic grains of augite.

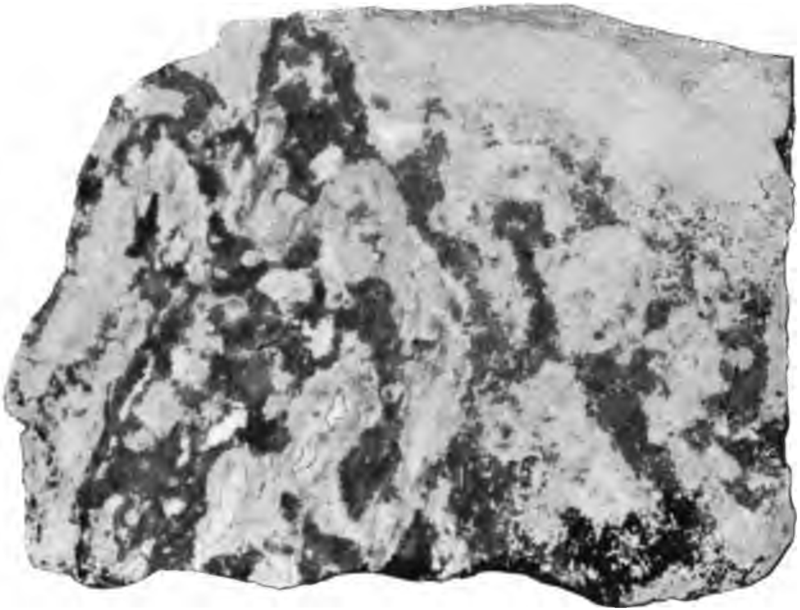
In certain small zones the augites show less pleochroism, presumably from possessing a smaller percentage of iron. In the shonkinite the ægirine exists as an occasional narrow border zone to the augites.

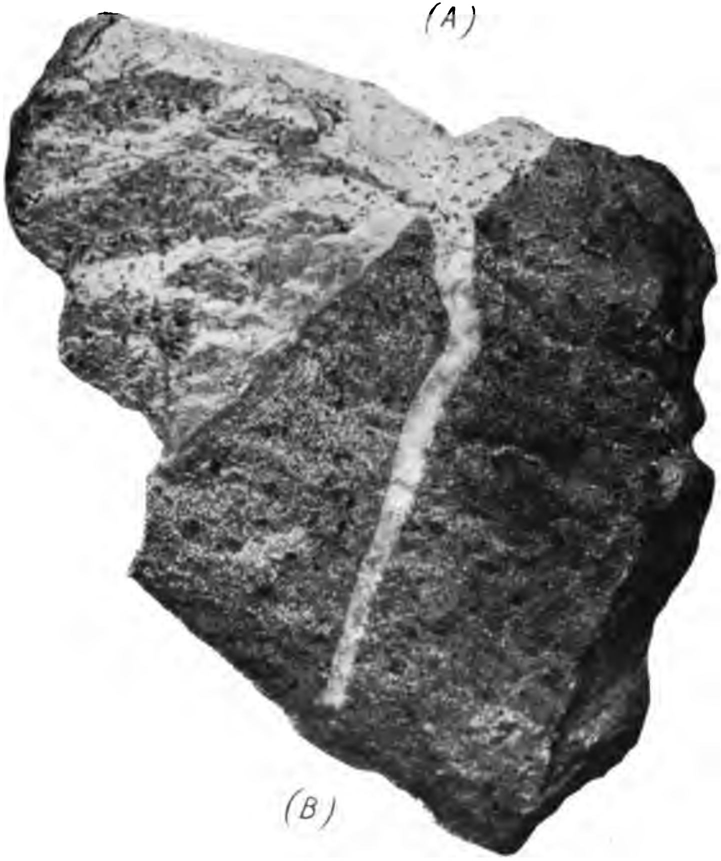
The mica in the syenite from the Elkhorn mine is pale green in color, quite unlike the rich brown of the shonkinite biotite.

The titanite in these rocks is abundant and occurs in the usual lozenge-shaped crystals, averaging 0.3 mm. in length. In A, however, the Elkhorn syenite, it also occurs in anhedral grains, and these are so closely intergrown with a brown garnet that it is only under polarized light that they can be clearly separated.

This close association of the crystals suggests that before crystallization the two may have existed in segregations of somewhat similar molecules, differing from each other in that one kind possessed iron, the other titanium, the two substances on crystallizing being forced to separate owing to their different habits of crystallization.

Titanium is known to occasionally replace iron and silica in andradite, and where it rises to a high percentage and alumina is absent the mineral becomes schorlomite. Titaniferous andradite contains from 1 to 10 per cent of TiO_2, and has been noted in Colorado and at Magnet Cove, Arkansas, as well as at a number of foreign localities. Schorlomite contains from 12 to 22 per cent of TiO_2, and occurs at





A. AUGITE-SYENITE. NATURAL SIZE.

Showing segregation of microscopic augites suspended in microcline and zone of iron-poor augites on the borders of the segregations.

B. APLITE STRINGER PENETRATING ANDESITE. NATURAL SIZE.

Proving later age of the aplite.

Magnet Cove. The relationships of these minerals are seen on comparing the formulas:

Titanite	3 CaO,	3 TiO_2,	3 SiO_2
Andradite garnet	3 CaO,	Fe_2O_3,	3 SiO_2
Titaniferous andradite	3 CaO,	$(FeTiAl)_2O_3$,*	3 $(SiTi)O_2$
Schorlomite	3 CaO,	$(FeTi)_2O_3$,†	3 $(SiTi)O_2$

These relations suggest that in the garnets of the Elkhorn syenites there is probably a considerable admixture of TiO_2. In the specimen from the mine the garnet shows an intergrowth also with the mica.

The garnet occurring in the bostonite is colorless in thin section, and contains fibrous inclusions, which may be wollastonite, as well as a very little calcite. In both places it shows intergrowths with other minerals, and in the bostonite is often poikilitic in the orthoclase. Garnet has been frequently noted in granites and syenites, as well as in gneisses, schists, and hornfels, and therefore no great weight need be attached to its occurrence here; but the absence of its proper crystalline form is exceptional, at least for this district.

On examining the mineral composition of the syenites, as given in the table, the decrease in the alkaline feldspar in C and D is seen to be due to the rise in iron, lime, and magnesia, which, by forming plagioclase and augite, have taken up certain amounts of the alkalies. The marked drop in D is seen to be due to a proportionate formation of biotite, owing to the combination of a considerable amount of potash with iron and magnesia.

These dikes within the isolated mass of metamorphic rocks show no relation to the eruptives which border it on all sides and are evidently more ancient than the latter. They point to some parent reservoir of a syenitic magma which has not been detected and may still lie concealed beneath the surface, or which has possibly been removed by the later intrusions that culminated in the formation of the batholith.

DIFFERENTIATION IN PLACE.

The variable character of these dikes in close juxtaposition, and especially the spotted and mottled surfaces shown in the augite-syenite, and which are reproduced in Pl. LXII, *A*, indicate that extreme differentiation readily takes place. The low percentage of silica indicates a considerable liquidity and the coarseness of texture presumably a leisurely crystallization, two conditions which may be taken as favorable for differentiation. Over certain patches, which may be a foot or more in length, no augite is present, and the rock shows only large and prominent cleavage faces of white feldspar. Surrounding such a white nucleus the microcline is so thickly charged with the augite crystals that the color becomes a blue-black, and the cleavage faces of feldspar on a close examination are seen to be thickly speckled with the included crystals. In the parts where the dark augites are abundant are many smaller spots, half an inch in diameter, free from them, giving a mottled appearance to the whole. The mottling of the augite-syenite does not appear to be due to the intimate admixture of previously differentiated acid and basic forms of the magma, but to a differentiation in place. This is judged from the character of the mottling, and is shown in Pl. LXII, *A*.

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* Dana, System of Mineralogy, 1892, p. 443.

† Op. cit., p. 447.

The contact of the white and blue-black varieties does not show the rounded and drawn-out forms which an admixture of viscous magmas would produce, but, on the contrary, it is an interwoven contact in which the white nuclei pass out in many knotted streamers and form on the surface spots showing a certain parallelism for a width of several inches.

There is a third and intermediate form of the rock, occurring as zones from an eighth to a quarter of an inch in thickness, between the two varieties previously mentioned. In the hand specimen the intermediate zone is seen to be light green in color, and under the microscope the reason is found to lie in the lighter color of the augite crystals, indicating the presence of a less amount of iron.

The segregation has originated, therefore, in place and before the beginning of crystallization. That it originated in place is shown by the form of the two kinds of areas; that it occurred before the beginning of crystallization, and was not produced merely by the settling together of the augite crystals already formed, is shown by the different character of the augites in those two zones where they occur.

The feldspars in growing have shown no power to exclude or even to orient the numerous small crystals of augite and titanite which they include, and thus the same crystal of orthoclase may contain portions of all three zones. It is consequently seen that the crystallization of all the minerals has taken place after the segregation and independently of it. In view of the fact that the augite crystals were considerably heavier than the liquid feldspar within which they formed, it is difficult to understand why a settling out did not take place; but that it did not is shown by the white nuclei being bordered by the dark material on the upper as well as the lower side. For such a differentiation to have taken place within the dike before crystallization, the magma must have presumbably been held for some little time liquid, a condition which implies a general high temperature of the rocks and the near presence at that time of a considerable volume of igneous material, the same condition being indicated by the coarsely crystalline rock structure.

Such a segregation within a narrow dike is in contrast to what has been observed in the Crazy Mountains and which is to be described in a report upon that district by J. E. Wolff and W. H. Weed.[1] There in the same dike occur three varieties derived from the same magma: First, a theralite; second, an acmite-trachyte or the sölvbergite variety of a tinguaite; and, third, a bostonite. The first two exist as inclusions in each one of the others, the bostonite probably acting as a cement to both. The fact that each holds inclusions of the other is taken by the authors as evidence that a mixture of the two, holding fragments already solidified, was intruded as a dike, and hence it is concluded that the differentiation took place before intrusion.

ANDESITES.

The andesitic intrusive sheets, lavas, breccias, and tuffs play a conspicuous part in the geology of the Elkhorn district, which they once covered in large part, if not entirely. They still occupy considerable areas adjacent to it, but within its limits have been largely removed by erosion and are now isolated into three distinct areas. The first occurs on the summit of Elkhorn Mountain, attaining a thickness of a thousand feet or more, and extending north and east beyond the limits of the district. The second is an isolated patch but 500 feet in diameter situated in Queen Gulch, 1½ miles east of the town and on the eastern boundary of the area mapped. The third is an area lying chiefly beyond the map, but of which one end occupies Turnley Gulch, in the extreme southwestern corner. The individual beds, especially of the northern area, show a striking range in mineral composition and manner of origin, grading from quartz-diorites to augite-andesites, and from intrusive sheets to tuffs, whereas the general character of the three areas mentioned is strikingly similar. The andesites present typically a dense, dark, and fine-grained appearance. They are highly elastic to the blow of a hammer, difficult to break, and are cut by numerous cleavage planes which, upon weathering, produce a sharp, angular, and resistant débris. On the highest and most rugged mountain slopes the individual blocks measure several feet in diameter, are heaped together without order, and form rude stairways by which one may readily climb. Here and there rocky promontories, 50 to 100 feet in height, rise from the general talus slope, while in other places the talus is composed of angular material but a few inches in diameter. On flatter declivities and at lower elevations, where the soil has an opportunity to form and the slopes are covered with grass or forest, the surface is smooth and the andesitic nature of the underlying rock is shown only by the finely broken and rust-colored angular material. A close examination of the larger blocks exhibits their original character, whether lavas, breccias, or tuffs, though the natures of the latter are obscured, from having been subsequently metamorphosed and hardened. The lavas are dense, fine-grained rocks, with but little evidence of bedding, sometimes possessing many labradorite phenocrysts, but always with an abundant groundmass. The latter is never coarsely crystalline, and in the first solidification was probably often glassy, though subsequent reheating has in all cases given it a microcrystalline texture.

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[1] Cf Judd, Composite dikes in Arran: Quart. Jour. Geol. Soc., Vol. XLXI, 1893, p. 536.

All transitions from lavas to breccias are found, though careful examination is often necessary to discriminate the latter, owing to the fact that fragments and groundmass have assumed the same finely crystalline texture in later crystallization.

The tuffs, though departing widely from the common character of tuffs, may be detected by being somewhat softer and lighter than the other andesitic rocks, and by usually showing fine-grained bedding planes, from various admixtures of ash and dust.

In contradistinction to the purely extrusive forms, intrusive sheets of andesite may be found interbedded with them. Sometimes the intrusive nature is demonstrated by the structural geology; at other times it is made probable, where the sheet was thick, by the greater coarseness of crystallization. Often, however, the two modes of occurrence can not be separated, since a thin intrusive sheet may not differ in any particular from the deeper parts of an extrusive flow.

ELKHORN MOUNTAIN INTRUSIVE ANDESITES.

In taking up the petrography of the andesites in detail, the undoubted intrusive forms will first be dealt with. The two great slabs of marble from the Madison formation, contained within the andesites of Elkhorn Mountain, and described in detail elsewhere, are separated by an intrusive sheet of andesite 80 to 100 feet in thickness. In outcropping, this forms a rounded summit 9,000 feet above the sea and 2,000 feet west of the extreme peak of Elkhorn Mountain.

An analysis, by H. N. Stokes, of this intrusive sheet is given and is compared with a couple of closely similar andesites:

Analyses of andesites from Montana and Yellowstone Park.

Constituent.	A.	B.	C.
SiO_2	59.64	60.30	59.48
Al_2O_3	16.64	16.31	16.37
Fe_2O_3	2.33	4.35	3.21
FeO	4.35	1.41	3.17
MgO	2.10	2.39	3.29
CaO	4.59	5.62	4.88
Na_2O	3.31	3.99	3.30
K_2O	4.16	2.36	2.81
H_2O- (at 110° C.)	.14	1.86	2.01
H_2O+ (above 110° C.)	.69	.64	
TiO_2	1.08	.76	.93
CO_2	None.	....	....
P_2O_5	.49	.20	.41
SO_3	....	.10	....
S	[a].01	....	....
Cr_2O_3	None.	Trace.	.03
MnO	Trace.	.13	.19
NiO	....	....	Trace.
BaO	.10	.15	.13
SrO	.05	Trace.	....
Li_2O	Trace.	....	....
	99.68	100.57	100.21

[a] Undetermined whether sulphide or sulphate.

A. Andesite from Elkhorn Mountain, Elkhorn, Montana. Analysis No. 1858. Field No. 42. H. N. Stokes, analyst.

B. Hornblende-pyroxene-andesite from Sepulchre Mountain, Yellowstone National Park. Contains augite, hypersthene, plagioclase, hornblende, magnetite. Described by Iddings, Twelfth Ann. Rept. U. S. Geol. Survey, p. 633; also in Bull. Philos. Soc. Washington, Vol. II, p. 210; and in Mon. U. S. Geol. Survey, Vol. XXXII, Pt. II. Analysis by T. M. Chatard.

C. Hypersthene-andesite, northwest of Red Bluff, Montana. Contains plagioclase and pyroxene, with an amorphous glassy base and sometimes olivine altered to chloritic matter. Collected by A. C. Peale and G. P. Merrill, Bull. U. S. Geol. Survey No. 168, p. 114.

The analysis shows the Elkhorn Mountain andesite to be of normal character with the exception of the high potash, in this respect showing affinities with the latites of F. L. Ransome, and perhaps having some significance to the later intrusion of quartz-monzonite. In the hand specimen it appears as a dark-gray, almost black, microcrystalline groundmass, in which is sprinkled a small amount of plagioclase phenocrysts that never exceed a millimeter in length. Under the microscope these are found to be very basic, probably corresponding on the average to a bytownite, and to possess on the outer borders a very narrow zone of a rather acid plagioclase. The phenocrysts are original, but the remaining structure of the rock bears marks of the crystallization having been imposed by contact metamorphism, and this is readily explainable when the nearby presence of the batholith and its far-reaching contact effects are recalled.

The groundmass consists for the most part of a mass of feldspar laths from 0.1 to 0.2 mm. in length, while sprinkled like a veil over all the rock, both phenocrysts and groundmass, are flakes of biotite and hornblende. These tend to be confined to strings and patches over the plagioclase phenocrysts, and are taken to show a recrystallization during a period of intense metamorphism, accompanied by a dissemination of the elements of the hornblende and biotite into the cracks of the feldspars.

Crystals of pyroxene are present but are rare, and a little magnetite occurs associated with biotite. Small amounts of analcite and natrolite are found as alteration products. An original faintly marked flow structure still shows. Although this rock has suffered from metamorphism, that action has resulted in no chemical changes, and the small amounts of water present indicate that it has not been altered appreciably by surface weathering. Beds of this character compose the western slopes of Elkhorn Peak, lying stratigraphically above the marbles as well as between them. At the summit the grain of crystallization becomes coarse and the rock is really a microdiorite, though still of the same series.

Lime-rich augite-andesites occur in a number of beds of unusual character on Elkhorn Mountain, consisting of a fine-grained light-gray groundmass, which may or may not contain plagioclase phenocrysts. The light color is due to the absence of all dark minerals, the rock consisting of plagioclase feldspars, orthoclase, zeolites, and colorless beads of augite, the latter indicating a poverty in iron and a richness in lime, and the orthoclase a similar richness in alkalies. The chief significance of these beds is in regard to the possibility of an addition of lime from a sedimentary source, and for that reason they will be fully considered in another paper in connection with that subject and will here be only briefly described. Specimens were taken from two horizons, the lowest, 15 feet in thickness, lying but a few feet above the Mesozoic marbles and lime-silicate rocks at the head of Elkhorn Gulch, thus being near the base of the andesite extrusive series; the second is from a bed 30 feet in thickness lying some distance above the former.

The phenocrysts in the lower bed are of plagioclase, but in the upper are of soda orthoclase, and in both rocks the feldspars have grown through the accession of numerous augite beads without showing any power of exclusion or orientation. The finely granular groundmass consists of feldspar, which is presumably strongly alkaline, together with the augite. Hypersthene is of rare occurrence. Epidote and zeolites are of secondary origin, and quartz is present also, but is probably due to infiltration.

ELKHORN MOUNTAIN LAVAS, BRECCIAS, AND TUFFS.

Between a thick surface flow of lava and a sheet of the same material intruded near the surface it is difficult to discriminate, and for present purposes it is unnecessary to seek to draw the exact line between them. Both are undoubtedly present upon Elkhorn Mountain.

Where the andesite contains brecciated material, either as broken crystals or angular fragments of previously solidified andesite, it may be taken as extrusive in origin. The tuffs consist of a mixture of volcanic dust and angular fragments of lava. When such have become indurated and crystallized the rock is frequently difficult to discriminate from lavas with a devitrified and metamorphosed glassy base holding a breccia.

At the southern limit of the Elkhorn Mountain area the basal beds of the andesite series are tuffs, and over all the southern ridge of Crow Mountain and to the east of Elkhorn Peak, tuffs and breccias are the most abundant rocks. These tuffs have suffered so greatly from metamorphism that at present all are dense, hard, and dark. The breccias show their character on a close examination of the surface, angular fragments being outlined by slight differences in color. The tuffs have a softer and smoother base and in the latter the brecciated material is not so abundant nor so coarse.

Under the microscope the lavas containing brecciated material are seen to be rocks of medium basicity, carrying a good deal of labradorite in broken crystals and fragments of microcrystalline andesites with lesser amounts of siliceous hornstones. The hornstones exist as small angular fragments approaching quartzites in composition, and in polarized light stand out clearly from the matrix.

The andesite fragments, on the contrary, often nearly resemble the groundmass and might readily be overlooked. In none of these breccias are broken fragments of other minerals than labradorite observed, nor in most cases have they formed afterwards from the groundmass. The interpretation to be placed upon this absence of the dark minerals is that at the time of eruption the labradorite crystals were the first to form and were floating as phenocrysts within a molten andesite. Upon eruption the crystals were sometimes blown into the air by the explosive forces of the escaping gases, along with bits of glassy and newly solidified andesite and also of hornstones which had been torn from the strata, these, with the accompanying dust, forming beds of tuff and breccia. At other times the phenocrysts and glassy fragments floated out in the lavas, the latter cooling so quickly that they became either glassy or microcrystalline, thus preventing the formation of other minerals of sufficient size to be identified.

QUEEN GULCH RESIDUAL AREA.

This small area of andesite, only 400 feet wide by 500 feet long, lies on a steep hill slope at a considerable distance from any other occurrence, and 1½ miles directly east of Elkhorn. There are a number of varieties present, but all agree in being rocks with an abundant, finely crystalline groundmass. In certain beds the flow structure is strongly marked, the flow planes dipping S. 55° W. at an angle of 30°. One abundant variety of this rock is so charged with tabular crystals of labradorite averaging three-eighths of an inch in diameter that the waterworn float bowlders are conspicuous in the stream beds for a mile below. Other varieties are dark green and spotted with small crystals of hornblende and labradorite. The forms of the andesite are the same as those noted on Elkhorn Mountain and discussed under the head of "Elkhorn Mountain intrusive andesites," these differing on the whole, however, in being so conspicuously porphyritic.

TURNLEY GULCH ANDESITES.

The edge of this area occupies the southwest corner of the mapped area (Pl. XLV), and forms steep, grassy hill slopes along Turnley Gulch. A sample for analysis was taken in the railroad cut a quarter of a mile south of the limits of the map and 70 feet from the contact with the upper surface of the diorite-porphyry laccolith. The analysis shows somewhat unusual proportions, and is compared with two others which resemble it in some respects, but depart from it in others.

Analyses of andesite and related rocks from Montana and Yellowstone Park.

Constituent.	A.	B.	C.
SiO_2	54.50	53.71	53.75
Al_2O_3	17.97	18.00	20.75
Fe_2O_3	[a]8.55	3.99	4.50
FeO	[b]Undet.	4.05	3.53
MgO	3.37	5.19	3.76
CaO	9.36	6.88	7.18
Na_2O	2.34	3.50	4.16
K_2O	1.62	3.10	1.37
H_2O at 110° C	.14	.55	1.55
H_2O above 110° C	.96		
TiO_2	.94	.74	None
CO_2	None.		None
P_2O_5	.31	.38	.15
SO_3			Trace
Cl			None
S	.63		
Cr_2O_3	None.		
MnO	Trace.	.24	Trace
BaO	.06		
SrO	.05		
LiO_2	Trace.		Trace
	[b]100.80	100.33	100.70

[a] Contains indeterminable amounts of both pyrite and pyrrhotite, the actual amounts lying between 1.59 Fe_7S_8 and 0.00 FeS_2 and 1.19 FeS_2 and 0.00 Fe_7S_8. FeO can not be directly determined, the 8.55 per cent Fe_2O_3 including the Fe_2O_3 equivalent of FeO and sulphides. The actual FeO lies between 5.39 and 6.46, and the actual Fe_2O_3 between 1.19 and 0.00.

[b] Summation too high because Fe in FeO and sulphides is stated as Fe_2O_3, the actual excess being indeterminable.

A. Hornblende-andesite-porphyry, altered from an augite-andesite and approaching a basalt in composition, from southwestern part of the Elkhorn district. Analysis No. 1858. Field No. 35. H. N. Stokes, analyst.

B. Mica-gabbro, Hurricane Ridge, Absaroka Range. Contains plagioclase augite, hypersthene, biotite, magnetite, with some orthoclase, and a little quartz and olivine. Described by Iddings in Mon. U. S. Geol. Survey, Vol. XXXII, Pt. II. Analysis by Eakins. See Bull. U. S. Geol. Survey No. 168.

C. Basalt dike, north spur of Mount Washburn, Yellowstone National Park. Reported by Iddings as approaching pyroxene-andesite in composition. Contains labradorite, augite, serpentinized olivine, and magnetite in a groundmass of globulitic and microlitic brown glass. Bull. U. S. Geol. Survey No. 168, p. 110.

The hornblende-andesite-porphyry in A has suffered greatly from alteration, produced in large part by contact metamorphism; but, as shown by the absence of carbon dioxide and the small amount of water present, its composition must closely represent the original. The phenocrysts consist of plagioclase and hornblende. The plagioclases are a labradorite and exist in two forms: (1) The crystals united in clusters up to 2 mm. in diameter, which sometimes show radiating arms, forming fragile and complex crystalline aggregates, and at other times are grouped in clusters without branches, in total amount these crystals form about 10 per cent of the composition. (2) Abundant lath-like crystals, which are from 0.3 to 0.5 mm. long, idiomorphic, and which exhibit a strong zonal structure; these comprise about half of the bulk of the rock.

The phenocrysts contain many inclusions filled with granular hornblende. The form of the inclusion cavities is determined by the feldspar, the cavities being oriented to the crystalline system of the latter. Inclusions of such form in feldspars are of common occurrence in rocks with a glassy base.

Phenocrysts of hornblende or augite have once existed and were of a later growth than the feldspars, but their places are now sometimes filled with granular hornblende of no orientation, suggesting decay of the original mineral and then recrystallization. At other times the hornblende remains in its original system, but the form of the crystals and the character of the rock make it appear clear that the hornblende is a product of uralitization from pyroxene. The groundmass also consists entirely of the same granular hornblende, both brown and green in color. All of these occurrences of this mineral, comprising about 40 per cent of the rock, confirm the impression that the original crystalline character, with the exception of the feldspars, has been entirely altered. Combining the information derived from the microscopic study with that from the chemical analysis, it may be concluded that the rock was originally a glassy pyroxene-andesite-porphyry which approached a basalt in composition. The iron ore, consisting of pyrite and pyrrhotite, with perhaps magnetite, is scattered in granules through the groundmass.

This andesite is quite different in composition from that of Elkhorn Mountain, of which the analysis was given, but the variable character of these lavas has already been pointed out, and the type under consideration is evidently one of the more basic forms, but just to what extent it is typical of all the andesites of this area is difficult to state. Its alteration from contact metamorphism is plainly due to the laccolith which lies immediately below it and of which it formed the cover. The andesites of this area present, on the whole, a much more uniform appearance than those of Elkhorn Peak. Breccias are occasionally observed, but the predominant type consists of an andesite-porphyry, in which the labradorite phenocrysts are usually small and few, but occasionally become a conspicuous feature of the rock. The groundmass is finely crystalline and in some cases has the appearance under the microscope of a devitrified glass.

In the tongue which projects eastward from the main area nearly half a mile and ends in the railroad cut, the rock assumes a coarser crystallization, becoming a microdiorite. A specimen taken from its terminus gives the following mineral composition, estimated by volume under the microscope:

Mineral composition of microdiorite.

	Per cent.
Labradorite	70
Augite	4
Hornblende	8
Biotite	12
Iron ore (magnetite)	2
Quartz	4
Total	100

The labradorite is strongly zonal, an indication of considerable soda within the rock, and the large amount of biotite is a similar evidence of potash. The latter mineral gives the rock somewhat of a kersantitic tendency, and it is principally in that feature that it differs from the dikes cutting the limestone strata on the north and east.

DIORITE-PORPHYRY LACCOLITH.

In the southwestern portion of the district, lying principally in Queen Gulch, is a considerable body of a diorite-porphyry, laccolithic in its manner of intrusion. Its bottom is the isolated fragment of Starmount lime-silicate rocks, forming a plane dipping 42° to the southwest, the dome-like cover consisting of andesites which have been partly removed by erosion. The bottom of Elkhorn Gulch at its junction with Turnley Gulch is cut well down into it, but the principal exposure is in Queen Gulch, where it attains a thickness perpendicular to its walls of 1,300 feet.

The rock presents a conspicuous appearance, consisting of about 30 per cent of labradorite phenocrysts and several per cent of biotite and hornblende, the latter two minerals in clusters, giving a spotted and mottled surface. The phenocrysts are embedded in a fine-grained crystalline groundmass, gray in color.

Under the microscope the rock is seen to strikingly resemble that composing the laccolith of Steamboat Mountain in the Little Belt Mountains, Montana.[1]

No analysis was made of this rock, and in default its mineral composition by volume is given as estimated by the microscope. While the percentages are, of course, not exact, the character of the rock is clearly indicated.

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[1] Geology of the Little Belt Mountains, by W. H. Weed, with report on petrography by L. V. Pirsson: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. III, 1900, pp. 383, 515.

Mineral composition of rock of diorite-porphyry laccolith.

	Per cent.
Labradorite	33
Biotite	3
Hornblende	3
Pyroxene	.3
Apatite	.3
Iron ore	1
Groundmass:	
Quartz	10
Plagioclase	20
Alkaline feldspar	30
Total	100.6

The composition of the feldspars of the groundmass is necessarily estimated with some uncertainty. To describe the peculiarities of the minerals more in detail: The feldspar phenocrysts are from 1 to 4 mm. in diameter and show a very strong zonal structure. The greater part is a rather basic labradorite, varying from Ab_1 An_2 to Ab_3 An_4, intergrown perthitically with an andesine. Over the parts which are intergrown the extinction is constant. After a certain time in the period of growth, however, the residual liquid could not or did not supply any longer the more basic feldspar molecules, and then the period of zonal growth began, the composition of the added shells of feldspar passing from andesine to oligoclase, and from the latter to albite, the extension of the lines of albite twinning to the extreme boundaries proving that no monoclinic feldspar exists in the outer zones. The noticeable feature of the zonal growth is its wide range and large amount, running as it does through nearly the whole series of the plagioclase feldspars. The transition is not always regular, a more basic zone sometimes surrounding one slightly more acid. Some of the feldspars contain many small inclusions within the labradorite interior, consisting of an acid plagioclase with a nucleus of hornblende, probably resulting from the rapidly growing crystal inclosing small portions of the magma which finally crystallized into the feldspar and hornblende.

The biotite is older in formation than the hornblende. With the latter it is collected into irregular clusters containing the iron ore and apatite also, and giving the dark, spotted appearance to the rock.

In one instance a well-bounded prismatic crystal of hornblende is observed, 5 mm. long and quite different in outline from the ragged crystals normally present. This prism has nuclei of brown hornblende throughout, surrounded by green hornblende possessing the appearance of an alteration product. Such a difference in habit in the same thin section between crystals of the same species may be taken as evidence of growth under different physical conditions, and this may be an instance of a hornblende phenocryst formed before intrusion, in contradistinction to the others formed afterwards.

Pyroxene is sparsely present, occurring in small, colorless, anhedral crystals associated with the apatite, and sometimes present as inclusions within the feldspars.

The feldspar of the groundmass embraces about 50 per cent of the entire rock. In so far as it can be separated it consists of about 40 per cent of small plagioclase crystals, showing either a rod-like form or chunky crystals with lines of albite twinning. Another 40 per cent of this groundmass feldspar consists of somewhat dusty, chunky crystals showing no albite twinning and taken to be orthoclase. The other 20 per cent is orthoclase intergrown with quartz and forming a well-developed micrographic structure.

The basic character of the phenocrysts in this rock is to be noted, standing in contradistinction to the rather acid character of the groundmass, and from a consideration of the former alone a very erroneous idea of the composition would be obtained.

TURNLEY RIDGE STOCK.

The Turnley Ridge stock is a very irregular and branching intrusion running for about two miles across the southwestern corner of the district and varying in width from several hundred feet to a half mile. In its northern part it consists of two arms, which hold a series of altered shales and quartzites between them.

The surface débris, by which it may be readily recognized, consists of angular blocks a foot or more in diameter, of a chalky color where not stained light brown and red from ferric oxide. It is a rock readily susceptible to weathering without disintegration, yielding surface material rather light in weight and giving a dull sound when struck with the hammer. A feature by which the rock may be recognized consists of numerous crystals of quartz, a tenth to a twentieth of an inch in diameter, scattered through the groundmass. These not being subject to the subaeriel decay which attacks the other minerals, show the greasy quartz luster and irregular fracture and are readily noted upon a close examination of the hand specimen. Besides the quartz crystals, which form about 15 per cent of the volume, the rock contains about 40 per cent of rectangular crystals of oligoclase, weathered to a chalky white. In favorable situations, as in the deep railroad cut on Elkhorn Gulch, material may be obtained which has not been affected by weathering. On such a fresh unweathered surface the groundmass, which composes about 40 per cent.of the entire volume, is seen to be dense and of a light-gray color. Even where unweathered, however, the feldspar phenocrysts are dull and lusterless. A microscopic examination shows that the rock has been greatly altered by mineralizing waters, which have not only given this appearance to the feldspars, but have utterly destroyed the several per cent of dark minerals which were originally present, and have finally resulted in the formation of considerable pyrite. A partial analysis of a specimen as nearly unaltered as could be found, taken from the railroad cut 6,000 feet south of the Elkhorn station, gave the following results:

Partial analysis of quartz-diorite-porphyry.

[H. N. Stokes, analyst. Rec. No. 1658. Field No. 7.]

	Per cent.
SiO_2	67.44
Al_2O_3 (including P_2O_5)	16.79
Fe_2O_3 (total iron)	2.10
Na_2O	4.19
K_2O	4.20
H_2O	1.48
LiO_2	Trace.
Total	96.20

Allowing for the destruction of the ferromagnesian minerals and taking the average of a number of sections, the original mineral composition has been estimated by volume as follows:

Mineral composition of quartz-diorite-porphyry.

	Per cent.
Oligoclase	40
Quartz	15
Hornblende	2
Biotite	2
Groundmass (quartz and feldspar)	41
Total	100

There is usually a sharp distinction between the phenocrysts and groundmass, the latter being a micrographic mixture of quartz and feldspar, the former possessing sharp idiomorphic boundaries several millimeters in diameter, though certain of these may be cleavage faces and not those once terminating the crystals. The feldspar phenocrysts possess an average diameter of 2 mm., usually show albite twinning, and range in chemical composition from a sodic labradorite to albite. Orthoclase is present in some parts of the intrusive and may form a minor part in others. Oligoclase, however, is the common type of the feldspar phenocrysts.

The quartz phenocrysts average 1 to 2 mm. in diameter, exhibiting, when unbroken, straight crystalline sides rounded on the corners. Their principal growth took place before the intrusion into the present locality, since many fragments show a crystalline outline on one side and an irregular fracture on the other, and sharp fragments, the débris of broken and dragged crystals, are common. The extinction is sharp and not undulatory, showing that the fracture has not been accompanied by great stresses. This is to be expected, since in a viscid medium a body would be pulled apart or sheared rather than crushed with straining of the crystallographic orientation. In most places considerable solution of the quartz, sometimes resulting in smooth, gibbous forms, has taken place after the crystals came to rest and before the final solidification. Upon the crystallization of the groundmass the small particles adjacent to the quartzes have oriented themselves against them, giving, when seen under a high power, a fine-grained, serrated margin. Within the tongue on the southern side no quartz phenocrysts are found, a fact worth noting, considering the evidences elsewhere that the quartzes are older than the intrusion. It may be due to the tongue being filled by material of the first advance which was retained there, while elsewhere within the stock the present rock may perhaps represent later accessions which alone contained the crystals of quartz.

The biotite has been completely resorbed by later processes, there remaining within the original outlines a sprinkling of micrographitic feldspar with small grains of iron ore and flakes of biotite. Certain sections show fairly numerous splinters of hornblende, but these, occurring especially within the feldspar phenocrysts, have the appearance of being of secondary origin, and that which remains as an original component is probably rare.

There is abundant muscovite, especially near the contacts, scattered over the section and resulting from alteration of the feldspar. The appearance is quite different from the dust-like flakes of kaolin which have resulted especially from surface weathering. In this rock the muscovite is sharply bounded, transparent, and scattered over the whole section through phenocrysts and groundmass, leaving clear and transparent those parts of the feldspars not occupied by it.

BATHOLITH AT ELKHORN.

The rock of the batholith occupying the northwestern quarter of the district is not uniform over large areas, but in places assumes a granitic phase, and, especially near the margins, often becomes a diorite. Predominantly, however, it is a quartz-monzonite with the field appearance of a dark granite. An article dealing with the general characteristics of the rocks of the batholith and embracing a study of the analyses made from various places has been published by Weed,[1] and consequently but little need be said here upon that topic.

For purposes of analysis, material was collected on the western margin of the district, a mile from the contact with the sedimentary formations. The analysis shows a very close agreement with that of the Butte granite and also with that from Clancey Creek, but is somewhat more basic than the prevailing type of the Boulder granite.

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[1] Granite rocks of Butte, Mont., and vicinity, by W. H. Weed: Jour. Geol., Nov.-Dec., 1899, p. 737.

The analyses from those localities are brought together for purposes of comparison.

Analyses of rocks from the Boulder batholith.

	112.	6 (*a*).	98 (*a*).	518 (*a*).
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	64.31	64.05	64.17	67.12
Al_2O_3	15.44	15.38	15.25	15
Fe_2O_3	2.43	2.20	2.16	1.62
FeO	2.58	2.74	2.98	2.23
MgO	2.21	2.08	2.60	1.74
CaO	4.22	4.30	4.24	3.43
Na_2O	2.71	2.74	2.62	2.76
K_2O	4.09	4.00	4.34	4.52
H_2O at 110° C	.19	.83	.65	.58
H_2O above 110° C	.79	.27	.16	.09
TiO_2	.71	.60	.67	.48
CO_2	None.	.35	None.	None.
P_2O_5	.22	.21	.16	.15
SO_3	....	....	.97	Trace.
Cl	....	....	Trace.	....
S	*b* Trace.	.07	....	....
Cr_2O_3	None.	....	....	....
MnO	Trace.	.11	.04	.06
BaO	.07	.08	.07	.07
SrO	Trace.	.04	Trace.	.03
Li_2O	Strong trace.	....	....	....
Total	99.97	100.05	100.18	99.88

[a] Granite rocks of Butte, Mont., and vicinity, by W. H. Weed: Jour. Geol., Nov.-Dec., 1899, p. 737.

[b] Whether S or SO_3 undetermined.

No. 112. Type of the batholith at Elkhorn, 1 mile from the contact.
No. 6. Butte type of granite, Butte district; H. N. Stokes, analyst.
No. 98. Head of Clancey Creek, northern part of batholith; H. N. Stokes, analyst.
No. 518. Prevailing type of granite of batholith at Boulder; H. N. Stokes, analyst.

The rock whose analysis is given under 112 resembles the Butte granite as closely in appearance as it does in chemical composition. It is a rather cross-grained rock, showing about equal amounts of hornblende and biotite, quartz existing in smoky grains and the feldspars with gray to pink cleavage surfaces. Under the microscope the plagioclase is seen to range from an andesine, $Ab_5\ An_4$, to a sodic labradorite, $Ab_1\ An_1$, existing in idiomorphic but not well-formed crystals from 1 to 3 mm. in diameter. The orthoclase and quartz are, as usual, the final products of crystallization, the former containing some soda. The apatite, magnetite, augite, hornblende, and biotite are associated together, the apatite being the earliest mineral to crystallize, then the augite, the latter forming very irregular nuclei in the interior of many hornblende crystals. The hornblende preceded the biotite in crystallization, and the formation of these three minerals resulted in the simultaneous separation of magnetite. The latter exists in grains averaging a third of a millimeter in diameter and also as a dust sprinkled through certain of the hornblendes. The small amount of titanite present belongs also to the earliest mineral generation.

Variations in texture.—The rock of the batholith varies both in texture and in composition. The type which was analyzed is rather coarse grained and without any evidence of gneissoid or flow structure. At other places not far distant, however, and forming a type perhaps equally abundant, the rock, without changing noticeably in composition, shows a faintly parallel arrangement of the dark minerals, which gives it a somewhat gneissoid structure. This variety does not show any intimate relation to the contact, though perhaps more abundant within a mile of it. In the vicinity of the contact, and forming a zone of variable width, the rock becomes finer grained, though no case has been observed within the district, or elsewhere at the margins of the batholith, where a distinct porphyritic structure is assumed.

The principal effect of the contact has been to cause a more or less simultaneous growth of the minerals, which gives an approach to the sugar-granular structure, and the quartz and orthoclase are also sometimes poikilitically interwoven.

Variations in composition.—The lamprophyric facies are not so strongly marked as is frequently the case, but still are noticeably present. Throughout the entire contact and for distances of a quarter of a mile from it the rock usually shows a greater predominance of plagioclase, and often of ferromagnesian minerals. These contact facies may be hardly noticeable to one traveling over the country, but become evident upon comparing specimens from different points, the transition being by a shading of one type into another and not by marked contrasts.

The limits of the variations are brought out in the table of comparisons on the next page, the rock from four points along the contact being compared to that of which the analysis has been given. The rock never becomes more basic than a diorite, and the amount of dark components is not greatly increased. Slight differences in composition, however, may in some cases cause hornblende to become the ruling species, and at other times biotite. The most constant differences on approaching the contact lie in the increase of plagioclase and the decrease of quartz, indicating a rise in alumina and a fall in silica.

At other places on the margins of this batholith, where contact facies approaching the gabbros have been observed, they have been often found in bays entering into the sedimentaries, and the absence of such within this district, at least in evident connection with the parent batholith, may be the reason for their failure to occur. The analyses[1] of two such forms from Red Mountain, 10 miles south of Butte, show 49.22 and 56.41 per cent of silica, respectively.

The table shows the mineral composition by volume as estimated by the microscope, a method sufficiently accurate to bring out the general variations which are under discussion.

Varieties of granitic rocks of the Boulder batholith within the Elkhorn district.

	112.	138.	56.	164.	38.
Labradorite, Ab_1 An_1	34	49	40	62	40
Andesine, Ab_5 An_3	....	....	....	....	15
Orthoclase with Na_2O	22	10	30	5	20
Quartz	25	10	16	15	5
Biotite	7	21	8	18	1
Hornblende	9	7	5	....	17
Augite	2	2	....	....	....
Magnetite	1	1	.5	....	2
Apatite	.3	.1	.1	.1	.1
Titanite	.5	....	.1	....	....
Rutile	....	....	Trace.	....	....
	100.8	100.1	99.7	100.1	100.1

No. 112. Quartz-monzonite. Type of batholith, 1 mile from contact, on western limit of map. See analysis on page 536.

No. 138. Diorite. From batholith. Originally, perhaps, 100 feet from contact with limestones; at present separated by aplite dike 400 feet wide. From point 2,500 feet north of Black Butte triangulation point.

No. 56. Quartz-monzonite, rich in feldspar; 100 feet from contact with andesite; northeast corner of map.

No. 164. Quartz-mica-diorite; 20 feet from contact with hornstone inclusion; half mile southwest of Black Butte triangulation point.

No. 38. Diorite; 50 feet from the quartz-diorite-porphyry stock of Turnley Ridge: on western limit of map 1 mile north of southeast corner.

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[1] Granite rocks of Butte, Mont., and vicinity, by W. H. Weed: Jour. Geol., Nov.-Dec., 1899, p. 739.

APLITES.

The aplites, as the term is commonly understood, are rocks of a sugar-granular texture due to a fine-grained, simultaneous crystallization of quartz and orthoclase, the rock consisting of those components with little or no ferromagnesian minerals. The term is ordinarily limited to sheets or dikes intrusive in granitic rocks and regarded as acid segregations from the original magma. In the larger masses the normal texture may fail and the rock become granitic, so that the intrusive nature and the intimate relationship with the main granitic mass must be relied upon as the final test.

The usual form of their occurrence in the area of the batholith is as thin dikelets a few inches in width, fairly numerous, with sharp, even contacts, and traceable for some distance. Where one terminates there is often an offset and the line is extended by another dike a few feet to one side. The texture is fine grained and of the sugar-granular type.

More abnormal forms of occurrence are as flat, lens-like masses, as at Butte,[1] but not found within the Elkhorn district, or as dikes several hundred feet in width with a granitic texture and parallel to the contact, as at Elkhorn. The chemical composition, as well as the texture, shows considerable variation, so that the basic varieties of the aplites may approach the acid forms of the original batholith intrusion, and the only safe criterion for discrimination lies in a study of the contact, the acid forms of the original magma passing into other varieties by gradations, while the aplites always show sharp contacts and evidences of later intrusion. The aplites are commonly believed to be acid segregations out of the original magma, here a quartz-monzonite, and it is supposed that their intrusion immediately followed the solidification of the greater parts of the batholith.

The aplites of the Elkhorn district occur as thin seams over most parts of the batholith area, but near the margins, as previously mentioned, they become dike-like intrusions of great volume. Analyses were made from the center and near the contact of that one which has broken through the quartz-monzonite north of Black Butte and which covers the greater part of the area for a quarter of a mile in width. The analyses show that the outer parts of the intrusion are more basic than the center, but are still clearly aplites. The chemical composition is remarkably similar to that of the Butte aplites, situated in the same batholith, but at a distance of 33 miles to the southwest, corresponding to a like similarity which was pointed out as existing between the quartz-monzonite of the two districts.

The resemblance of these types to the granodiorites and granulites of the Sierras has been pointed out by Weed.[1] An analysis of one of the Sierra granulites (aplites) is added for purposes of comparison.

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[1] Description of the Butte Special district, by W. H. Weed: Geologic Atlas U. S., folio 38, 1897.

Analyses of aplites from Montana and California.

	109.	142.	640.	192.
SiO_2	76.26	74.61	76.87	75.97
Al_2O_3	12.94	13.36	12.52	13.07
Fe_2O_3	.69	.83	.67	.61
FeO	.13	.36	None.	.39
MgO	.17	.35	.09	.14
CaO	1.10	1.35	.49	1.49
Na_2O	2.73	2.49	2.47	2.51
K_2O	5.26	5.70	5.78	5.62
H_2O at 110° C	.17	.19	.52	.24
H_2O above 110° C	.43	.42	.25	.14
TiO_2	.11	.11	.11	.09
CO_2	None.	None.	....	....
P_2O_5	.06	.06	.05	Trace.
S	[a].01	[b]Trace.	....	....
Cr_2O_3	None.	None.	....	....
NiO	None.	....	....	....
MnO	Trace.	Trace.	....	Trace.
BaO	.07	.10	....	.14
SrO	None.	Trace.	....	Trace.
Li_2O	Trace.	Trace.	....	Trace.
Total	100.13	99.93	99.82	100.44

[a] Total S. [b] Whether sulphide or sulphate undetermined.

No. 109. Aplite from middle of large intrusion, 1,000 feet west of batholith contact, north of Black Butte. Analysis No. 1858. Field No. 109. H. N. Stokes, analyst.

No. 142. Aplite from eastern side of same intrusion, near inclusions of quartz-monzonite, 2,500 feet north of Black Butte. Analysis No. 1858. Field No. 142. H. N. Stokes, analyst.

No. 640. Aplite of Butte granite, Butte, Mont.

No. 192. Granulite (aplite) dike east of Milton, Sierra County, Cal. Collected and described by H. W. Turner. W. F. Hillebrand, analyst. See Bull. U. S. Geol. Survey No. 168, p. 192.

In general the aplites of the Elkhorn district show the sugar-granular texture and consist of soda orthoclase and quartz, with a few per cent of plagioclase and occasional crystals of biotite and magnetite. The plagioclase is an andesine and is idiomorphic; the quartz and orthoclase, however, have grown simultaneously and neither has been able to assume its proper crystallographic form.

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[1] Granite rocks of Butte, Mont., and vicinity, by W. H. Weed: Jour. Geol., Nov.-Dec., 1899, p. 740.

The biotite usually forms from one-half to 2 per cent, and occurs in thin scales averaging 0.3 mm. in diameter. The lack of clustering in the biotite is characteristic and gives a finely speckled appearance to the rock.

ELKHORN MOUNTAIN APLITE.

The above petrographic description applies entirely to the northernmost intrusion, a thick sheet lying between the quartz-monzonite and the andesites of Elkhorn Peak. The aplite in its contact against the andesite forms a sharp and even surface and shows evidence of chilling against the latter rock. At the immediate contact a zone of aplite an inch in width is fairly coarse grained, with quartz and feldspar poikilitically intergrown and possessing a considerable amount of biotite. This coarseness is evidently due to the contact surface offering a passage for the escape of vapors, whose influence in inducing a coarser crystalline structure is well known.

Following the narrow band of coarse-grained aplite is a zone several feet in width with an indefinite inner boundary characterized by a radiate poikilitic intergrowth of quartz and orthoclase, the mixed grains being 2 mm. in diameter. There is much less biotite than at the immediate contact. A thin section taken 52 inches from the contact showed certain crystals of orthoclase which became poikilitic only after half their growth was completed, indicating a change in the physical conditions at that period, owing to which the quartz and orthoclase could no longer separate themselves from each other during crystallization, and were of simultaneous growth. At a distance of 20 feet the aplite shows its normal sugar-granular character.

The importance of these contact phenomena lies in the proof they furnish that the aplite is younger than the andesite.

The aplite stock.—In the aplite stock penetrating the sediments 6,000 feet southwest of Elkhorn Peak the aplite structure is nearly lost and the rock assumes the appearance of an acid granite. It has no visible contact with the quartz-monzonite and consequently its aplitic affinities are based solely upon its mineral and chemical composition. The change in texture is no doubt due to the large diameter of the stock, which permitted a thorough heating of the walls and a prolonged period of crystallization.

APLITE DIKES NORTH OF BLACK BUTTE.

In the system of dikes which have broken through the quartz-monzonite lying north and west of Black Butte, the normal type of aplite is that given in analysis 109, on page 540. It is an acid granite, with but little biotite and but little of the sugar-granular texture. It shades into two prominent varieties, one of which approaches the pegmatitic, the other the porphyritic type of structure. The former occurs at places in the center of the intrusions, and one locality was noted where the biotite showed a great extension along one of the horizontal axes, forming thin blades, half a millimeter in width by 12 to 15 mm. in length. The other variety is found near the margins of the intrusions, an analysis of it being given as No. 142, on page 540. It is finer grained, shows the typical aplite structure, and is richer in biotite, the latter existing in scales and not in clusters. Within the immediate vicinity of the margins, however, clusters are formed which resemble those of the quartz-monzonite.

APLITE DIKES SOUTHWEST OF BLACK BUTTE.

The aplites occurring at intervals along the margin in the southern part of the district show the normal character, except at one locality half a mile southwest of Black Butte, where phenocrysts of a soda orthoclase, an inch in diameter, are abundant. The crystals are poikilitically intergrown with quartz, which is visible in wavy lines to the naked eye and constitutes about a quarter of the volume of the crystal. By the exclusion of the biotite and plagioclase molecules from the area of the phenocrysts, the aplitic groundmass is correspondingly enriched in those components.

CONTACT DIKES OF APLITE IN TURNLEY GULCH.

A few dikes of aplite cross Turnley Gulch, barely within the limits of the map. They are of medium width, and lie between the quartz-monzonite and the andesite. Stringers from them penetrate the andesite and prove in the most unequivocal manner the younger age of the aplite, and therefore also of the quartz-monzonite. This deduction gives them great importance, and hence one is illustrated in Pl. LXII, *B*.

SEGREGATIONS OF TOURMALINE.

At a number of places within the aplites, especially on the road to Elkhorn Peak, at an elevation of about 8,000 feet, and near the borders of the intrusions north of Black Butte, crow-foot segregations of a black mineral are observed. These are usually about 1 inch in diameter, but may be from 4 to 6 inches across. Sometimes they are irregular, dendritic forms, at other times circular or rhomboidal in outline. The segregations are intermixed with quartz and orthoclase, and under the microscope are found to consist of a dark tourmaline, without crystal boundaries. The tourmaline areas are always surrounded by a white zone from one-half to 1 inch in width, from which the dark components have evidently been exhausted, beyond which the aplite assumes its normal appearance and possesses its scales of biotite. The boron and fluorine of the tourmaline, indicative of pneumatolitic action, and especially associated with contact surfaces, have combined with the constituents which otherwise would have formed the mica, and the width of the white zone marks the power of migration which the molecules have shown in coming together to form the segregations.

ALTERED SEDIMENTARY (CONTACT-METAMORPHIC) ROCKS.

USE OF NAMES.

For the results of contact metamorphism there is a lack of generic and specific names, as most of the names which are applied to metamorphic rocks denote species which have been subjected to dynamic action, and which differ conspicuously in appearance from those formed by the contact action of heated masses without the superimposed effects of deformations. Of the names used more particularly in describing the results of contact action "quartzite" has a definite meaning, being applied to a metamorphosed sandstone which, to make a typical quartzite, should be fairly free from lime or alumina. "Hornfels" is used as a rather general term tò include the metamorphosed products from shales, slates, or clays. The word "hornstone" is nearly equivalent, but is also applied to flint or chert, and its use is therefore objectionable. "Marble" is the result of metamorphism of a rather pure limestone.

Taking the three predominant constituents of the sedimentary rocks as lime, alumina, and silica, it is seen that for the various metamorphosed admixtures of the three, forming very diverse rocks, there are no good group names, and there is a poverty of those having specific value. On dividing the sediments into five chief groups according to their composition, the following names are seen to apply:

Composition.	Name.
1. Silica	Quartzite.
2. Silica-alumina	Hornfels, or hornstone.
3. Silica-lime	Lime-silicate rock.
4. Lime-silica-alumina	Lime-alumina-silicate rock.
5. Lime	Marble.

Since alumina does not occur in rock masses except in association with silica, there are no alumina or lime-alumina groups.

To eliminate as much as possible the rather clumsy term of lime-alumina-silicate rock, the name of the predominant mineral may be employed as an adjective. Thus one may speak of a grossularite,[1] a vesuvianite, or a labradorite rock, as the case may be.

The metamorphosed sediments will be treated in groups according to composition, and not chronologically, the divisions being taken up in the order in which they have just been named.

QUARTZITES.

PURE QUARTZITES.

The pure quartzites are grayish-white rocks, finely granular and having a vitreous luster upon fresh fracture. The purest beds within the Elkhorn district are found within the Quadrant quartzites and at the top of the Cambrian quartzite.

From this pure type, which is relatively rare, there are departures in several directions. Small amounts of kaolin, orthoclase, and undecomposed rock are commonly present in the original sandstone as a clay-like filling, and upon metamorphism these turn into biotite and feldspars. On the other hand, there may be soluble materials within the sandstone, and their removal and the presence of silica-bearing waters may result in a further deposition of silica and ally such replacement quartzites to the vein quartzes.

QUARTZITIC HORNSTONES.

Those metamorphic rocks which approach most nearly to the quartzites, but differ from them in having originally possessed an admixture of clay and undecomposed rock fragments, are dark in color and present the appearance of a finely granular eruptive rock. Examples of this type are found in the middle member of the Turnley series, originally a fine-grained shaly sandstone. The rocks now consist of about 15 per cent of olive-green flakes of microscopic biotite and 85 per cent of quartz. The color is due to the dark mica, and the fracture is somewhat sugary, from the great abundance of quartz (field No. 22).

The greatest coarseness of crystallization in rocks of this composition is observed in those places where they are adjacent to the granite. One such (field No. 4) under the microscope was found to consist of 70 per cent quartz, 10 per cent acid plagioclase feldspar (probably all oligoclase), and 20 per cent deep-brown biotite in plates up to half a millimeter in length. The crystals show the mutual indentations due to simultaneous growth, a feature characteristic of quartzites and hornstones, and the carbonaceous matter is scattered dirtily through the feldspars. The most typical representatives of this group of metamorphosed sediments are found within the Mesozoic, where they show as hard, prominent ledges which only the trained geologist could with certainty distinguish from eruptive rocks.

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[1] Grossularite is a lime-alumina garnet; it varies greatly in color, but in the Elkhorn rocks is usually pale brown, or, more rarely, green. Vesuvianite is a basic lime-alumina silicate, carrying ome iron.

A bed of dark, coarsely granular rock which should also be grouped under this heading was noted in the Turnley shales, the lowest sedimentary horizon of the district (field No. 20). Under the microscope it is seen to consist of extremely irregular anhedrons of quartz and feldspar from 1 to 2 mm. in diameter. The feldspars are predominantly alkaline and are very irregular in composition, giving an uneven extinction under crossed nicols. Unlike the other quartzitic hornstones, the crystal individuals are not clearly separated from one another, but show extensive intergrowth. The biotite crystals show the form characteristic of hornstones and are scattered through the feldspar, sometimes composing half the volume, in other places existing in clusters. The uneven distribution of the biotite causes the rock, when seen in plain light in thin section, to resemble an arkose, but such an appearance may be an effect of crystallization. There is considerable groundmass, mostly of a feldspar.

The greater freedom of crystallization which this rock shows may be due to its being a stratum readily permeable to rising vapors.

HORNSTONES.

The hornstones, as the name is here used, include those metamorphosed rocks that are rich in silica and alumina—rocks which in their original state belonged to the clay series. They always carry with the alumina a considerable amount of alkalies, lime, magnesia, and iron, and upon reconstitution consist predominantly of quartz, biotite, and feldspar, the character of the rock changing with the relative amounts of each and the coarseness of crystallization.

Those hornstones rich in argillaceous matter are much softer, and in the field may resemble argillaceous limestones. The content of lime, however, has always been low, and in their metamorphosed state they never effervesce with acid. They have been originally shales, and the two great changes which have taken place are a loss of the fissile nature and often a marked change in color, the latter being due to a clearing up of the groundmass through crystallization into feldspars or quartz, the collection of the organic matter in dots affecting the color less than if disseminated, and, lastly, the color given by microscopic biotite flakes set up throughout the section. The Union shales show these differences well, since north of the town they exist with their original black fissile character, but on the southern side of the Cemetery Ridge stock they are soft rocks of a purplish-red color (field No. 10), without much cleavage, and with a fine-grained splintery fracture. Under the microscope this hornstone is seen to consist of the following components:

	Per cent.
Light-brown biotite flakes	25
Quartz grains	4
Graphitic pigment, in opaque strings and grains	2
Microgranitic feldspar and quartz groundmass	69

The lowest member of the Turnley series is a somewhat similar hornstone, of a lighter purplish red, consisting of 33 per cent of biotite flakes and 67 per cent of finely granular quartz. Its fissile character has not been entirely destroyed. Within the Mesozoic series similar beds are found, one being noted of a slate-blue color.

LIME-ALUMINA-SILICATE ROCKS.

The lime-silicate and lime-alumina-silicate rocks are of great hardness, and in color range from white to pale brown, green, or yellow. They indicate their large percentage of lime by showing under the microscope essentially the lime-silicate minerals. Usually not more than three such minerals constitute the bulk of any one rock, though the species vary according to the composition of the strata. Those of commonest occurrence are grossular-garnet, diopside, wollastonite, vesuvianite, and lime-soda feldspars.

Wherever the strata are of the proper composition they may be metamorphosed bodily for distances of several hundred feet from the igneous contacts, with the formation of certain of these minerals and the expulsion of the carbonic acid.

The Starmount argillaceous limestones are the lowest strata of this character. South of Black Butte, and extending from there to Elkhorn Gulch, they are seen in occasional outcrops, and at other places are exposed by erosion of the soil. The bedding planes are still evident, but the rocks are hard, and sometimes show coarse crystals of pale-green diopside, at other times pale-brown garnet in banded lens-like masses or in sponge-like growths. South of Elkhorn Gulch there is but little metamorphism within the main mass of sediments, but within the fragment isolated between the quartz-diorite-porphyry and the diorite-porphyry laccolith the final degree has been reached.

The impurities of the strata have been sufficient to combine with all the lime, completely expelling the carbonic acid.

The average composition of these rocks is about as follows:

	Per cent.
Grossularite	45
Diopside	20
Wollastonite	10
Lime-soda feldspar	10
Alkali feldspar	15

The next horizon showing great alterations of this character is that of the Keene limestones at their contacts with the Cemetery Ridge stock. These rocks being less argillaceous than the Starmount limestones, the garnet sinks to a subordinate amount and the siliceous impurities combine with the lime and magnesia, predominantly as a pyroxene and no doubt approaching a pure diopside in composition. That the silica of the Keene metamorphic rocks was not derived from the neighboring magma is indicated by the contact on the northern side of the stock against the Madison limestones. Here the limestone, being free from impurities, exists still as a carbonate rock to within a foot or so of the contact.

A large part of the Mesozoic hornfels series, as is shown in the detailed section given elsewhere, consists of metamorphosed strata belonging to the lime-alumina-silicate group.

LIME-SILICATE GROUP.

The simplest case for study is that of a limestone containing a small amount of silica. This type is not uncommon, since it is seldom that the marbles are absolutely pure. A thin section from a marble inclusion within the quartz-monzonite (field No. 133) showed under the microscope about ·5 per cent of wollastonite and 4 per cent of another mineral decomposed to a white amorphous product.

The section is instructive as showing the manner of formation of the metamorphic minerals when they are few in number and therefore not restrained in their growth by other individuals of the same species. Ninety per cent of the rock consists of irregular anhedrons of calcite, averaging from one-half to 1 mm. in diameter, and containing many very minute scales, about 0.01 mm. in size, whose nature is not determinable. Wherever calcite has been observed in the metamorphic rocks of this district it is always allotriomorphic and the minerals projecting into it often show their proper crystalline form.

The wollastonite occurs scattered evenly over the section, the chunky prisms averaging a millimeter apart and a third of a millimeter in length. The extension is in the direction of the cleavage. Although the opportunities for free growth have here been exceptional, the wollastonite crystals do not possess well-formed faces but have all the corners smoothly rounded off, presenting a resemblance to waterworn pebbles. In their isolation from one another and opportunities for free growth, these crystals are analogous to the minerals of earliest generation within a magma, and their subidiomorphic outlines may be a characteristic of their metamorphic origin. In regard to wollastonite it must be said, however, that it is not a mineral of the earliest generation, since where it occurs in the presence of augite it exists as a cement to the latter mineral. When growing within a marble it may not assert itself with the same power as do some other minerals, notably garnet.

In the Keene limestones, at their contact with the Cemetery Ridge stock, as before noted, the original rock is a siliceous dolomite which upon metamorphism becomes a diopside rock, though probably containing some alumina. The diopside where existing free, either in calcite or in wollastonite, shows as clear, elongated, spheroidal beads, often not more than .01 mm. in diameter. Where it forms the bulk of the rock it exists as anhedrons rudely fitted together and without sharp corners. The usual size of the individual grains in such aggregates is about .05 mm., though sometimes they are much coarser.

ORDER OF CRYSTALLIZATION OF THE MINERALS OF THE LIME-ALUMINA-SILICATE GROUP.

When metamorphosed the rocks belonging to this group indicate their character by the presence of some lime-aluminous minerals, such as garnet, vesuvianite, epidote, and plagioclase. Although these rocks, like the hornstones, usually show a mutual restraint among all the minerals, yet certain species often exhibit somewhat idiomorphic outlines and indicate a definite order in crystallization.

Garnet is the mineral which oftenest has power to assume its proper form, and does so in the presence of all the other minerals. Augite, while molded by garnet, itself molds wollastonite (field No. 27). Calcite is often a secondary mineral, and in such cases fills miarolitic cavities or replaces some previous mineral, and is naturally in such cases highly allotriomorphic.

Where existing evidently as an original mineral (field Nos. 9, 146) it forms either a background for small crystals of other minerals, such as beads of augite, or exists itself in globular masses as inclosures within other minerals. It is never seen to assume its crystallographic outlines.

Occurrence of minerals.—The combination of species is determined to a great extent by the proportionate amounts of the elements in the rock, but besides this there are certain minerals which show a greater tendency to form than do others. Garnet is the most universal of these and is very common wherever the alumina and silica exist in proper amounts.

Where the garnets occur of microscopic size they do not show the sharp angles customary in larger specimens, but are of a roughly polygonal form. The usual size of the grains in the thin sections is from .05 to .10 mm., and where existing in considerable areas the grains are gathered together in mulberry-like clusters.

Vesuvianite is comparatively rare in the Elkhorn district. Its chemical composition is near to that of grossularite, and the latter, under the conditions prevailing in this region, has usually been the mineral species with strongest tendencies to form.

Where the composition of the original rock determines the formation of feldspars as a metamorphic product, these usually assume the form of anhedrons about .05 mm. in diameter, crowding one another closely and entirely allotriomorphic, forming a groundmass whose appearance is unlike that of an igneous rock. Microcline has been noted in larger areas, 1 mm. or more in diameter, the crystals showing watered effects, fitting against one another by irregular margins and including within them fragments of the other minerals (field No. 169). Such areas strongly resemble the occurrence of microcline in some syenites, and nothing but the field relations and appearance of the hand specimen decide as to whether the rock was originally igneous or sedimentary.

The most general distinction between the rocks of igneous and sedimentary origin lies in the usual allotriomorphic character of all the minerals composing the latter.

The mineral species are usually also distinct, and where alike occur in different percentages characteristic of the two classes. There are cases, however, where rocks of such widely different origins approach very near to each other in microscopic appearance.

MARBLES.

The marbles are composed of a mosaic of anhedral calcite grains of varying size, and contain small amounts of other minerals according to the nature of the impurities present, as, for example, the marble with small amounts of wollastonite present which has already been mentioned. Another marble, occurring north of the town of Elkhorn, shows in the hand specimen many slender black needles which under the microscope prove to be skeletal crystals of tremolite, the crystals being hollow and having grown through the marble without the power of excluding it from the interior.

From the previous petrographical studies it has become evident that even under the most intense metamorphism the carbonic acid is not expelled from the limestone except by the presence of silica and the other impurities which accompany it. This fact has been noted elsewhere by other observers, and disproves for the Elkhorn district any extensive migration of magmatic material into the sediments.

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